WHAT
IS
LIFE?

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CONTENTS

PREFACE ix

Part I—HOW WE WORK

✓ Is Man a Machine? 3
✓ Our Muscles 7
The Economics of the Body 11
✓ How the Heart Works 16
✓ How We Breathe 20
✓ Digestion 24
✓ Our Food Needs 29
✓ The Nervous System 33
The Dialectics of the Nervous System 37
Seeing 41
The Senses of the Skin 45
Hormones 50
✓ Growth 54
What is Life? 58

Part II—HEREDITY AND ENVIRONMENT

Eugenics 65
A Discussion at Princeton 69
Sex Education 74
✓ Is Sex Necessary? 78
✓ The Egg and the Chicken Most interesting 83
✓ The Origin of the Vertebrates 87
Uneven Development 92
Creative Mutation 96
✓ Animal Geography 100
✓ Animal History 105
✓ Men and Women 110
✓ Cousin Marriage 114
Race, Religion, and Crime 118
✓ Can We Change Human Nature? 123
Heredity and Environment 127

Part III—SCIENCE AND SOCIETY

✓ Why People Fear Science 133
Should Science Be Planned? 137
Planning and Freedom in Science 141
Can Science Be Taught? 145
Teaching Teachers 150
Women in Science 155
The Back Door to Science 159
Soviet Science 163

Part IV—SCIENCE FOR SOCIETY

Averages 175
Are Things What They Seem? 179
Shapes and Weights 183
Blood Donors in the Future 187
Defective or Deaf? 192
Life at High Pressures 196
Overcrowding and Undercrowding 223
Dry Heat and Wet Heat 227
Dusts 231
D.D.T. 235
A Cure for Tuberculosis? 239
War on Weeds 244
A Great Anniversary 249
The Layman's View of Nature 253

PREFACE

THIS BOOK CONSISTS OF A SERIES OF ARTICLES, MOST of which were first published in the *Daily Worker.* However, that on "Life at High Pressures" was first published in the Penguin Series, whom I have to thank for permission to republish, and that on the "Lay View of Nature" by the World Union of Freethinkers. It is no joke to have to write a weekly article on science for the general public. It may have had a good effect on me, by giving me an excuse to read what was going on in other branches of science than my own, and also to try to state some of my own results in simple words. The result of doing this was that I frequently saw new relations between facts and theories, which I subsequently worked out in scientific journals. Inevitably, in a popular article one must oversimplify, and I plead guilty to having done so. But I should like to point out that one often does so in a scientific paper, and perhaps with still more serious results. People write of the organs of *the* rabbit, as if they had dissected the Platonic idea of a rabbit; or of the average height of Londoners, as if there was one. In fact, since people are taller when they get up in the morning than when they go to bed, and as old Londoners die and new ones are born every few moments, it varies in a most complicated manner.

One cannot avoid making mistakes if one tries to produce a set of words, or of mathematical formulae, to describe nature. Nature is more complicated than language or mathematics. Nevertheless, one must do one's best to produce a set of symbols which are not too discordant with the facts. Younger men and women will doubtless do it better than I, and I shall not be sorry to give place to them. I only wish that other newspapers would publish regular weekly scientific articles, as the *Daily Worker* does. They might also imitate it in some other respects. Meanwhile, here is a sample. Criticise it by all means. But the best form of criticism will be to do a similar job, and to do it better.

J. B. S. HALDANE.

PART I

HOW WE WORK

IS MAN A MACHINE?

THE FRENCH PHILOSOPHER DESCARTES, THREE CENTURIES ago, was the first to say that men were machines. He thought that animals were nothing but machines, and men were machines guided by souls. The Greek and Roman philosophers did not have this idea, because they only knew of very simple machines, such as bows and pulleys. When such complicated machines as clocks were made the idea became much more plausible. It is obviously a useful idea, because we can ask the same sort of questions about the parts of our body as we do about the parts of a machine. What is the heart for, and how does it work? Its function is to pump blood round, as an oil pump pumps oil round in many motors. And it has valves and other parts like those of a pump. In the same way we can compare the eye with a photographic camera, the nerves with telegraph wires, the fat under the skin with the insulating material round a boiler, and so on.

The description of man as a machine is much more useful to-day than it was in Descartes' time, because in his day self-moving machines were worked by springs, like that of a clock, whereas now the best-known ones are worked by the burning of coal or petrol. The comparison between a man and an engine driven by coal or petrol is very close indeed, if we merely consider intake and output, and do not go into the details. Each requires combustible food or fuel and a large supply of air. In each case most of the food or fuel is combined with oxygen from the air and converted into carbon dioxide and water vapour. You can collect the exhaust gases from a man or a motor-cycle in a bag and analyse them. For the man and the machine you can make a very complete material balance-sheet; and, if the man has neither gained nor lost in weight at the end of a day, you can balance gain and loss very exactly.

If you put a man on a good balance-scale, such as is used for weighing gold bullion, no two swings are the same. He loses weight steadily. But this loss is exactly accounted for by the water vapour and carbon dioxide which he loses from his lungs and skin. What is much more interesting, you can make an exact balance-sheet for energy. On the credit side is the energy which can be got from oxidising the food. This can be measured very exactly by burning it in a calorimeter. On the debit side is the small amount of energy which can be got by burning the excreta, the amount of mechanical work which the man has done during the day, and the amount of heat which he has produced. Naturally the balance will be imperfect at the end of the day. A man may easily put on or lose a quarter of an ounce of fat. But in a series of forty days' careful experiments the total energy credits and debits for three men were equal to within one part in 450. We do not make energy, nor get it from any supernatural source. We use the energy derivable from the oxidation of food as a machine would. In consequence, the energy value of a diet is one of the most important things about it.

Human energy outputs and needs are usually measured in large calories, a calorie being the amount of heat which raises the temperature of a kilogram of water by one degree Centigrade. A very inactive man can carry on on under 2,000 calories per day, an ordinary worker on 3,000 or so. A coal hewer may need 5,000, and a racing cyclist will expend 10,000 though he will take several days to make it up by eating. A well-trained man doing hard work may reach a mechanical efficiency of about 20 per cent. That is to say, one-fifth of his energy output is work, and four-fifths heat. But as he can only work for part of the twenty-four hours, this average cannot be kept up. A steam or petrol engine can reach much higher values, but this is hardly a fair comparison. For the engine does not stoke itself, oil itself, do running repairs, and occasionally co-operate with another engine to make a little one. Much of our energy is spent in keeping ourselves in working order. For example, all the energy which the heart expands in pumping the blood round is ultimately converted into heat.

In these important respects, then, a man is a machine. It is worth while looking at some ways in which he is not. One of the essential features of a machine is that any part of it can be replaced by a spare part. This is only true to a small extent with men. If you try to graft a limb from one individual to another, it may heal into place, but it will die later on. On the other hand, you can graft together trees of different varieties or even different species. And, what is more striking, you can do the same with frogs if you operate on young embryos. A head from one species will grow on the body of another.

On the other hand, as the practice of transfusion shows, human blood can be used as a "spare part", provided certain precautions are taken. Again, if a man's pancreas goes wrong in a particular way, he cannot use sugar and wastes away with diabetes. But if he is given insulin made from a pig's pancreas, he recovers his health. Insulin is another spare part that we can use.

So it is more dialectical to ask the question "How much of a machine is man?" One can then answer in detail. Part of the answer would be that, as regards the use of spare parts, man is less of a machine than a tree or a frog, but still something of a machine.

OUR MUSCLES

UNDER OUR SKINS WE HAVE A VARIETY OF ORGANS, which are arranged according to much the same general plan as those of a rabbit, a cat, or a sheep, and still more like those of a monkey. With a microscope we can see that most of these organs are built up of cells. An average cell is about a thousandth of an inch across, of a shape like a short sandbag which has been squashed in an irregular heap. Single cells can be kept alive for many years in a suitable fluid, but nothing smaller than a cell will live for more than a few hours. In fact the cell is a living thing with its own internal organisation.

A large part of our bulk is made up of muscle, or what at meals we call meat. Most of our muscles only act when stimulated by nerves, and go completely flabby when the nerves are cut. These are all under control of the will. Others will either stay in a partly contracted state, or contract and relax rhythmically, when the nerves to them have been cut. These include the heart, and muscles in such organs as the stomach and the womb. They cannot be directly controlled by the nervous system. The voluntary muscles are almost all attached to bones, usually at both ends. But often there is a fairly long tendon between the muscle and the bone. Thus it is easy to verify that most of the muscles which move our fingers are in the forearm, with tendons passing through the wrist.

We can show that a muscle is a chemically driven machine by analysing the blood going into it through an artery, and coming out through a vein. The blood in the vein contains less oxygen and sugar, and more carbon dioxide, than the blood in the artery. In fact the energy of muscular contraction comes from the union of oxygen with sugar. How the oxygen and sugar get into the blood we shall see later.

Under the microscope we can see that a muscle consists of a number of cells lengthened out into fibres, each supplied by a single fibre from a nerve. The fibres contract individually, and the pull which a muscle exerts depends on how many of its fibres are contracting. Each fibre pulls as hard as it can if it pulls at all. The muscles act entirely by pulling, and one of the main functions of the bones of the limbs and lower jaw is to convert their pulls into pushes. It is easy by feeling someone else to verify the main muscles which contract when, for example, we strike out with our fists.

The muscles exert very large forces. For example, the distance from the hand to the elbow joint is about six times the distance from the elbow joint to the end of the biceps muscle. Thus if a man can lift his weight with one hand, his biceps could lift six times this weight if it were tied to the tendon; and the great thigh muscles are far more powerful.

Though the energy of a contracting muscle is ultimately supplied by the oxidation of sugar, this is not its immediate source. On the contrary, a muscle can do quite a lot of work if its blood supply is cut off; when working hard it actually liberates energy quicker than it can be supplied by oxidation. The immediate source of energy is the breakdown of an unstable substance called adenosine-triphosphoric acid, which makes microscopic fibrils in the muscle shrink, much as wool does. The adenosine-triphosphoric acid is then put together again as the result of a very complicated series of chemical processes. Model muscles will run on a supply of A.T.P. as it is usually called, but they are not a practical source of power.

A rough analogy would be as follows: Imagine a petrol motor charging an accumulator which in its turn works a dynamo which coils up a powerful spring. The motor will give five horsepower at most, and does so automatically until the accumulator is charged. But the accumulator will give ten horsepower for a short time and the spring even more for a second or two.

This is roughly what happens with our muscles. If you are running a hundred yards you go all out, and your muscles develop their maximum power. For some minutes after the race you breathe more than usual, and the muscles are taking sugar and oxygen out of your blood to recharge the accumulators and wind the springs. If you are running two miles you will keep a steady pace which is set by the maximum rate at which energy can be supplied to the muscles by oxidising sugar. The spring, to use the metaphor, is kept wound up, and the accumulator charged. At the very end you sprint, and, as it were, allow the spring to uncoil and the accumulator to discharge. If you sprint too soon, your muscles will be less efficient.

Thus the same muscles can do very hard work for a short time, and moderate work for much longer. Of course, the real mechanism is much more complicated than the analogy suggests.

In particular, the muscle has a store of sugar in the form of a kind of starch called glycogen, which it uses up during work, and it goes on taking up sugar from the blood long after it has satisfied its need of oxygen. This account, summary as it is, obviously raises a lot of questions. The most obvious one is, "How do the nerves make the muscle fibres contract?" But equally important are the questions of how the muscles are supplied with the oxygen and sugar which they need for work, not to mention scores of other substances which are required even to keep them in working order, let alone to allow them to grow. This brings us to the question of the economics of the body; that is to say, how the various organs are supplied with what they need, and how they get rid of their waste products. For every organ has its needs. The liver and kidneys, for example, are working all the time, more steadily than most muscles, but just as surely. We shall deal with these vital economic relations each in turn.

THE ECONOMICS OF THE BODY

THE MOST STRIKING AND OBVIOUS RELATIONS BETWEEN the parts of the body are through the nervous system. We move our leg when we want to do so, or involuntarily if we tread on a hot coal. And unconscious actions, such as sweating and digestion, have also been proved to be under nervous control.

But the chemical relations, corresponding to the economic relations between members of human society, are far more vitally important. You can cut the nerves to a leg and it will go on living, though the muscles will waste until the nerves grow again. But if you cut off the blood supply for a few hours, the leg will die, and unless it is amputated the whole body will rot.

Chemical substances pass from one part of the body to another mainly by the blood, but partly by a clear fluid called lymph, which drains into the bloodstream from the tissues through special channels.

You have probably a little over a gallon of blood. Nearly half the volume of the blood consists of red corpuscles, whose function is to carry oxygen. The rest is a yellowish liquid called plasma, which carries round other substances.

These include a number of proteins, whose molecules are too large to allow them to pass through the membranes of most blood vessels. The most striking fact about the substances which can get through is their extreme constancy. For example, the amount of sodium in a pint of plasma does not vary by more than about one per cent. between different people, or in the same person at different times.

The reason for this is an historical one. The blood plasma of a crab, a cuttlefish, or many other sea animals is of nearly the composition of sea water, and their hearts will go on beating for some time in sea water. If you kill a rabbit and cut the heart out, it will not beat in fresh water or sea water. But it will beat in sea water diluted with about two and a half parts of fresh water, and still better in an artificial solution which is an even closer imitation of plasma. Our cells demand an imitation sea water because their ancestors were accustomed to live in real sea water. They demand it diluted because when they came out of the sea, something over three hundred million years ago, there was a good deal less salt in the sea than there is now.

The salts in the plasma are mainly common salt, or sodium chloride, and sodium bicarbonate. There are small amounts of potassium, calcium, and magnesium salts, phosphates, and other components; even a little zinc and iron. These are essential. Without potassium the heart goes into cramp. Without calcium it will not contract. The bicarbonate is needed to balance the acidity which would otherwise be caused by the carbon dioxide produced in the different organs. Besides salts there are oxygen and foodstuffs on the way to organs which use them, waste products on the way out, and hormones going from one organ to another. The amounts of these, too, are astonishingly steady.

Our cells are specialists. They are extremely good at their job, whether it is doing mechanical work, chemical work such as secretion, communication, or thinking. They are much more efficient than isolated cells such as protozoa, which have to be Jacks-of-all-trades. But they demand a standard environment with an adequate supply of oxygen, food, and hormones, a steady temperature, adequate removal of waste products, and so on. A skilled mechanic produces far more per day than a savage. But he cannot catch or gather his breakfast, build his hut, and so on, as the savage can. These things are done for him by other skilled workers. Our cells are specialists in the same sort of way.

The great French physiologist, Claude Bernard, who discovered the sugar in blood, made the following statement: "All the vital mechanisms, varied as they are, have only one object, that of preserving constant the conditions of life in the internal environment." This is possibly an exaggeration, but not a very bad one.

Look at it this way. You work to earn wages, which are mainly spent on food, clothes, and rent. The clothes and house help you to keep your temperature constant. The food is needed to keep the foodstuffs in your blood constant. If you do not have a rotten tooth out, your blood will be flooded with various poisons. So it is lucky you have a toothache to warn you. If you do not wash you will be likely to get one of several diseases which have the same effect. If you hang yourself, the cells of your brain will get no oxygen, and you will die. Claude Bernard was a contemporary of Marx, and his generalisation has the same importance for physiology as Marx's economic interpretation of history has in political science. When we understand why the various constituents of the blood are needed, and how they are regulated, we know a good deal about how we work.

One of the functions of the kidneys is to regulate the amount of salts in the blood, and the other is to get rid of substances which are not wanted, including waste products. Each kidney contains about a million microscopic filters called glomeruli, through which blood flows. The filter holds back the corpuscles and proteins, but about a quarter of the plasma leaves the blood to pass down a tube. The walls of this tube are alive, and the cells reabsorb from the filtrate a standard fluid which is what blood plasma ought to be, and return it to the blood. Almost all the waste products are left behind to form urine. If you have just been eating salt, and your blood plasma has more than the standard amount, a concentrated salt solution is left behind. If you have been sweating and drinking water, the salt in the filtrate is below standard, so when the standard fluid is reabsorbed you produce a urine with no salt in it. The same process is applied to other constituents, such as sugar.

We can compare the tube to a conveyor belt, from which workers pick out what is wanted, and eave extras and waste products behind. The kidneys sift a volume about equal to the whole plasma every half-hour. The different units, consisting of a filter and tube, take occasional rests. At any particular time, a large fraction of them, often more than half, are shut down.

Some of the other organs work similarly in the "planned economy" of the body, which, so long as we are in health, ensures that every cell is supplied according to its needs.

HOW THE HEART WORKS

THE BLOOD TRANSPORTS SUBSTANCES FROM ONE PART of the body to another, and a study of its functions is a study of the productive relations of the different organs. We also know a good deal about how the various substances in it are made in different cells. Unfortunately this knowledge can only be explained in terms of fairly complicated organic chemistry.

Most educated people know roughly how the heart works. It is a hollow muscle, and consists of four chambers. The upper two, called the auricles, have thin walls, so that they are easily filled, but cannot pump at high pressure. The lower two, called the ventricles, have thicker walls, and it takes some pressure to force blood into them. But they can force it further on at high pressure. The right auricle gets blood from all over the body, the left one from the lungs only. They contract together, and fill the ventricles. The right ventricle forces blood through the lungs, the left ventricle through the rest of the body. The direction of the flow is determined by four sets of valves.

Thus, in a complete circuit, a blood corpuscle passes through an organ, such as a muscle or the brain, where it gives up oxygen needed by the tissues, returns to the right heart by veins, and is sent on to the lungs. Here it picks up oxygen, and goes on to the left heart, which pumps it through arteries to the same or another organ.

The heart has a natural rate of beat, which it preserves if removed from the body. One set of nerve fibres passes messages from the brain which slow it down; another set speeds it up. At rest it is beating slower than the "natural" rate. A special part of the brain, just where it joins the spinal cord at the back of the neck, regulates the rate. The normal regulation is carried out as follows. In several of the large arteries, including the aorta, which leads out of the left ventricle, and the carotids, which carry blood to the brain, there are pressure gauges. These consist of a group of cells, each attached to a nerve fibre. The higher the pressure, the more impulses go along these nerve fibres; and the more impulses that go up the nerve fibres, the more leave the brain to come down the nerves which slow the heart beat. This is a simple example of a reflex, and is, of course, done quite unconsciously. In consequence, the pressure in the large arteries is kept pretty steady.

Now suppose an organ begins doing work, for example, the stomach churning up a meal and making gastric juice, or my arm muscles playing their part in writing this page. Carbon dioxide is produced in the working cells, and this makes the small blood vessels through the organ open up. Thus the organ gets the oxygen it needs, and gets rid of carbon dioxide. As a result, the blood gets away from the aorta more easily, and the pressure falls.

Fewer impulses go out from the brain, and in consequence the heart speeds up until the pressure is restored to its normal value, which is about equivalent to four and a half feet of water in a young adult and more in an older one.

In fact, the left heart is constantly doing work equivalent to pumping the blood to a cistern about three feet above the top of your head. Such a cistern would be useful if we were always standing up. As we are not, a system of elastic tubes is more efficient. At rest, the average adult heart delivers a bit under a gallon a minute. During very hard work this may go up from six to nine or ten times, partly by speeding up the rate, and mainly by increasing the output per beat.

This is the normal situation at rest. Each organ gets as much blood as it requires. But if there is not enough blood to go round them all, a system of priorities is put into operation. There is muscle in the walls of most of the larger blood vessels, and it is under control of the brain. If you start taking violent exercise the circular muscles round the arteries to the viscera contract, and their blood supply is reduced to a trickle. For example, your kidneys may be very busy producing urine, but if you run a mile the secretion stops abruptly. Similarly you cease to absorb food from your intestine.

The priority, or vasomotor, system, as it is called, is used in another situation. You have to get rid of the heat produced by the various chemical processes in your body. You produce enough to raise your temperature by about three degrees Fahrenheit per hour if none gets away. Normally, we get rid of it easily, and wear clothes to keep it in. But if we produce more heat than usual, or the temperature outside rises, then special measures are taken. The arteries to the skin are opened full up, and the blood flow through it increases about ten times. Its temperature rises, and it loses far more heat than usual. Very often this skin flushing is accompanied by sweating, which is a very efficient way of keeping cool, provided the sweat can evaporate.

The brain and heart are privileged. There is no means of cutting their blood supply off, though it can be regulated to some extent. If the brain goes without fresh blood for even half a minute, we faint. Unfortunately in the standing position it is particularly liable to go short. especially when one cannot move one's legs, and the blood stagnates in them. That is one reason why sick people have to lie down.

The vasomotor system is normally outside voluntary control, though the phenomenon of blushing shows that the emotions interfere with it. However, it is very easily controlled during a variety of religious practices, such as those of dervishes, who cut themselves without bleeding. Probably an actress, such as Bette Davis or Beatrix Lehmann, who is an expert in portraying intense emotion, can control hers to a large extent. A good many people can weep at will; some can control their heart rate. In fact, the line is not at all clearly drawn.

But considering that the heart rate and the diameters of the various arteries are normally regulated so as to supply the different parts of the body fairly in the general interest, it is a very good thing that most people cannot interfere with this control.

HOW WE BREATHE

PRIMITIVE MEN THOUGHT THAT BREATHING AND life were the same thing, and this curious idea is embodied in our language. There are two Latin words for breath, *anima* and *spiritus*. Our words "animal" and "spiritual", derived from the Latin, are now used with contrary meanings though originally both meant "breathy".

Some simple organisms can live without any sort of breathing. Most of them use oxygen and get rid of carbon dioxide. The larger land animals do this through special organs, the lungs. We expand our lungs by moving the ribs, and by contracting a dome-shaped muscle, the diaphragm, between the chest and belly, which pushes the contents of the abdomen down, and sucks the lungs after it. Men use the diaphragm more than women.

The essential of human breathing is the exchange of gases between the lungs and the outer air. If the breathing muscles are paralysed this can be done artificially for years on end, if need be, with an "iron lung" which expands and contracts the chest artificially. It can even be done without moving the chest at all, by putting a man into a steel cylinder in which the air pressure is raised and lowered through about 5 lbs. per square inch gauge pressure about fifteen times a minute. When a man is put in this he soon stops breathing in the ordinary sense of the word. The expansion and compression of the air in his lungs is enough to carry out the necessary gas exchange.

The lungs are of a spongy structure with a total surface area of about 100 square yards. The membrane between blood and air is extremely thin, and is the most vulnerable part of our body. About one person in seven dies of lung disease due to infection, dust, or both, although the lungs have a very large factor of safety. One can live quite well with only one lung. More people die of heart disease than lung diseases. But that is because no large part of the heart is indispensable. You could not live for five minutes with only half a heart.

A resting man uses about half a cubic foot of oxygen an hour, and anything up to ten times as much during very hard work. He produces a slightly less volume of carbon dioxide. When the carbon dioxide in the inspired air gets above three per cent. the breathing gets deeper, when it reaches six per cent. one pants heavily. So, to take a topical example, if each man in a submarine has 400 cubic feet of air, during moderate work he will produce about a cubic foot of carbon dioxide every hour, and the crew will be panting badly after twenty-four hours if this gas is not removed artificially.

Both the oxygen and the carbon dioxide in the blood are mostly in chemical combination. You can get about 18 to 20 volumes of oxygen and 50 to 60 volumes of carbon dioxide with a pump from 100 volumes of blood. This means that a volume of blood carries round nearly as much oxygen as the same volume of air. The oxygen is combined with the red pigment haemoglobin, and this will not take up much more even if you breathe deeper and faster than usual, or breathe pure oxygen. Nor does it take up much less if the amount of oxygen in the air is slightly cut down, as when one flies at the height of a mile, though at two miles up it is better to breathe air with some extra oxygen in it.

The carbon dioxide is mostly present as sodium bicarbonate, and as various other weak acids compete with it for the sodium, your blood loses a lot if you overbreathe, and takes up a lot if you breathe air containing say seven per cent. of carbon dioxide. In either case you feel pretty queer. If you sit in a chair and breathe as deep and as fast as you can for a minute or so your fingers will probably begin to tingle. If you go on longer you will probably get cramp in your hands and feet. Some people get convulsions; and probably if every reader of this book tried it, one or two of them would die.

For your body to work normally you must have just the right amount of carbon dioxide in your blood and various organs. If you like to put it that way, carbon dioxide is both a poison and a necessity of life. The breathing is normally regulated so as to keep the carbon dioxide in the blood at a steady level. You pant if it rises above this level as a result of exercise. If it falls below it, you slow down your breathing, or even stop it, until it rises to normal again. There is a second regulating device which speeds up the breathing still further if the oxygen in the blood falls below the standard level; but this only comes into action during very hard work.

The blood coming to the brain is continually being sampled, partly by cells in the brain itself, and partly by a special organ situated along with the pressure gauge on the carotid artery in the neck; and breathing is a reflex depending on the composition of the blood.

In fact breathing is one of the many bodily activities which keep the internal environment of our cells steady, and as it is one of the easiest to study, it has thrown a good deal of light on the others. It is remarkable that this regulation goes on even when we are using our lungs for another purpose such as speaking or singing. Normally the regulation is quite unconscious. But if it is interfered with, for example, if we hold our breath, or breathe air containing seven per cent. of carbon dioxide, we develop an air hunger which gets priority over every other sensation. This is quite typical of how we work. Our minds pay little attention to our bodies as long as they are working normally but attend very quickly when certain things go wrong. Some demands are clear enough to our consciousness. We know whether we are short of air, water, or food. Unfortunately we are not so clear when we are short of some particular component of our food, such as trytophan or vitamin A.

This brings us to the discussion of digestion and diet.

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DIGESTION

WE NEED FOOD AS A SOURCE OF ENERGY TO DO WORK and keep warm, and also for growth and repairs. Some free-living single cells, such as an amoeba, can eat a great variety of foods. So can some of our white blood corpuscles, which do their best to remove foreign matter under our skins and to eat up dead tissue.

But most of our cells are specialists, and demand foodstuffs of standard types, dissolved in the blood. The function of our digestive organs is to keep up a standard level of the various foodstuffs in the blood. The most important of these, and the only one which we can yet estimate accurately by chemical methods, is sugar; not ordinary cane sugar, but glucose, also called grape sugar or barley sugar. If the amount of this in our blood falls below the standard, our stomachs begin to contract, and we feel hunger.

Sugar is our main source of energy, though fat is also an important one; but we also need an unknown number (probably more than thirty and less than a hundred) of other substances. These are partly used as sources of energy, but mainly for building up new living material. For example, we are continually making new skin as the old skin is rubbed away. Some of these essential chemicals can be made in our own bodies, others cannot. A green plant can make them all. We rely for them on the green plants, whether we eat plants, or the flesh of animals which have eaten the plants.

In our food most of these dietary essentials are built up into larger molecules. For example, in bread and potatoes the sugar molecules are joined up in long chains to form starch. We store sugar in our livers and muscles as a substance called glycogen, which is fairly like starch. But the pattern is rather different, and we have to break starch down to sugar before we can build it up to glycogen.

In the same way each animal and plant species builds up its characteristic proteins from about twenty types of molecules called amino-acids arranged in patterns which differ from one species to another, and to some extent within a species. A foreign protein injected into our blood is not merely useless. It is often poisonous, and we have special mechanisms to deal with it. Many of the symptoms of infectious diseases are due to the entrance into our blood of "foreign" proteins produced by bacteria, and some can be reproduced by repeated injections of other foreign proteins, such as egg white.

Digestion is simply the process of splitting up large molecules such as starch and protein produced by other species into smaller ones which pass through the walls of our gut into the blood, and can be used by our cells and made up into the chemical patterns characteristic of man. This splitting is carried out by a special set of proteins made in the various glands which open into our digestive organs. They are called the digestive ferments or enzymes, and have amazing properties.

For example, our stomach produces a ferment called pepsin which will digest fifty times its weight of protein per second, and keep up this rate for some hours. What is even more remarkable, it can reproduce itself. The glands in the wall of the stomach do not make pepsin. If they did they would probably digest themselves. They make a stuff called pepsinogen, which does not digest proteins. But if a little pepsin is added to pepsinogen it makes more pepsin, as a rabbit makes grass into more rabbit. Pepsin is not alive. But it shows some of the properties of living things, and more complicated proteins show still more of them. No one can draw a sharp line between living and non-living substances, and some of the properties of pepsin are shown by synthetic laboratory products.

Our food usually stays for some hours in the stomach, where pepsin and other ferments break it up into a soupy condition. Then it is gradually passed on into the small intestine, a tube about twenty feet long where more ferments complete digestion, and the small molecules formed pass through the wall into the bloodstream. The residue goes into the large intestine where most of the water is absorbed, and undigested residues are concentrated and finally thrown out of the body.

The digestive canal has its own set of muscles, including those which churn up the food, and pass it along, and sphincters at each end of the stomach and of the large intestine, which open when required. These muscles, and the various glands, are controlled by the nervous system, and also communicate with one another by hormones carried in the bloodstream. Nervous impulses come up to the brain; but except for those from the two ends, the mouth, throat and stomach and the rectum, they do not usually give rise to sensations. For we know when our stomach is contracting with hunger, and when our rectum, the last section of the large intestine, is full; and we take appropriate action. But messages from the rest of the intestines only get through to the consciousness when things are going wrong and we feel pain.

The liver secretes some digestive ferments, but its main function is storage and regulation. The blood from the intestines passes through it before going on to the heart. During digestion this blood naturally contains far more than the standard amounts of foodstuffs. It also contains some substances which would be poisonous if they accumulated in the blood. The liver takes up the excess of sugar and other nutrients, and stores them in its cells, where they are gradually liberated when the amount in the blood falls below the standard. It also makes ammonia, and some other poisons produced in digestion, into harmless substances.

We do not use all our food. Some fibres are indigestible, and some of the products of digestion are used by bacteria in our intestines. These make a number of ill-smelling substances, and waste some of our food. But they also make some nutrients which we need, such as vitamin K which is concerned in blood clotting, and of which we do not get enough in our food. Definitely harmful organisms, such as worms and typhoid bacilli, sometimes get into our guts and cause disease. I have little doubt that in a few hundred years we shall know enough physiology and bacteriology to keep our insides as clean as we keep our skins. This will mean a considerable increase in health, and the end of a number of smells which we take for granted at present. But we cannot yet achieve "inner cleanliness", in spite of advertisements, and would probably die of vitamin deficiencies if we did so. We cannot yet control what goes on in our guts, but we can control what we put into our mouths by a balanced diet.

OUR FOOD NEEDS

"TO EACH ACCORDING TO HIS NEEDS" IS THE FORMULA of scientific rationing. For man's needs for food are largely, though not completely, known, whereas his needs for clothing, housing, and so on, are not. For example, we know that lice can breed in underclothes if they are not washed about once a week. We do not know if it is of the slightest benefit to health to change them daily.

The first animal whose dietary needs were fairly completely worked out was the rat. Human needs are not quite the same as those of rats. For example, rats do not get scurvy if deprived of ascorbic acid, otherwise known as vitamin C, and men do. But men possibly do not need histidine in their proteins, certainly not very much of it, and rats require it.

First of all, man needs a diet which will give him enough energy to keep up his temperature and do his daily work. The energy provided by the food is measured in calories. The amount needed varies with the work done from under 2,000 for an invalid in bed to 5,000 or more for a coal miner or lumberman. This energy is mainly obtained from the oxidation of carbohydrates such as starch and sugar, and of fats, including butter and olive oil. Some is provided by the oxidation of proteins, and these are particularly useful in keeping us warm in cold weather.

Because human energy needs are so variable, it is most important that some articles of diet with a high energy value should be unrationed. We have always, even during the war, been able to get as much bread as we wanted in Britain and often as much potatoes and oatmeal. But very hard workers usually consume a lot of fat as a source of energy, and we have been short of fats. Probably the miners' demand for more meat is as much due to fat hunger as protein hunger.

A diet which is very low in calories leads to a considerable loss of weight, and ultimately to death from starvation. The prisoners at Belsen got about 800 calories per day; and no one could live for as long as six months on such a diet, even if he were doing no work.

Proteins are also needed for growth, if one is young or pregnant; to provide milk, if one is nursing a baby; and to replace wear and tear of living tissue, if one is an ordinary adult. And an ordinary adult needs about 70 grams, or two and a half ounces, of protein per day. But the quality is important, for proteins are built up of a variety of constituents called amino-acids, and some proteins do not contain all the amino-acids which we need. Milk, cheese, meat, and fish are good in this respect. The proteins of vegetable seeds such as wheat are not so good. So, though bread contains a fair amount of protein, some animal protein is needed as well.

Men who run short of proteins may live for a long time, but they develop various diseases. A very characteristic one is hunger dropsy, apparently due to a shortage of proteins in the blood plasma. This allows water to leak out of the blood into the body tissues.

We need much smaller amounts of a group of very various organic substances which are grouped together as vitamins. Our daily needs of ascorbic acid are about 75 milligrams, or just over a grain, per day. The best source is fruit. Potatoes contain enough to keep off scurvy, which results from a gross deficiency of this vitamin, though hardly enough for perfect health. We need about 20 milligrams a day of nicotinic acid, three milligrams of riboflavin, and a good deal less of a dozen or so other vitamins. A gross shortage of any one of them gives rise to a characteristic disease such as pellagra, rickets, or night-blindness, but a moderate shortage merely leads to slow growth and indefinite ill-health. These vitamins are found in a variety of foods. The main value of green vegetables is as a source of some of them. Others are naturally found in butter and artificially added to margarine. A monotonous diet is very apt to lead to a lack of one or other of them. The "points" system has has been an attempt to give some variety to every household.

Finally we need various minerals. A hewer in a hot mine may need about two ounces a day of common salt to make up for what he loses in his sweat. We also need about one and a half grams of phosphorus and nearly a gram of calcium; even more if we are making bone quickly. Milk is a good source of both. We need about twelve milligrams of iron in an easily absorbed form. Cocoa and liver are particularly good sources. A shortage can cause anaemia, particularly in women, who need rather more iron than men, as they lose more blood.

All these are very rough figures. Nursing and expectant mothers need more of most things; growing children, of many. There is no reason to think our knowledge is anything like complete. It is good enough to wipe out serious malnutrition. But it is not yet good enough to prescribe the best possible diet.

Let us see why:

A strain of rats at Columbia University, New York, has carried on for fifty-eight generations on a standard diet, of which they can eat as much as they want. By human standards it would be called an adequate diet. But when the amount of vitamin A in it was quadrupled, the average life of males increased from 652 to 723 days, that of females from 724 to 830 days. Still more striking, the average period over which females bore children was increased from 265 to 369 days. Substitute ten days for a year, and you get a rough human equivalent. Experiments on this scale with men and women are of course impracticable, but we shall not get at the facts until groups of hundreds of people have been kept on controlled diets for periods of several years, and their health records and fertilities compared. Such experiments will cost a lot, but less than an atomic bomb or even a battleship.

THE NERVOUS SYSTEM

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ALMOST ALL PARTS OF OUR BODY CONTAIN VERY FINE fibres running into bundles which are called nerves, and which can finally be traced into the central nervous system, that is to say the brain in the hollow of our skulls, and the spinal cord in the hollow of our backbones.

Each fibre can conduct messages either way, but usually does so in one direction only. Those which conduct messages to the central nervous system are called afferent fibres. They include sensory fibres, that is to say fibres whose connections with the brain are such that messages up them cause sensations of sight, sound, smell, touch, pain, or some other sensation. But some afferent messages cause no sensation, for example, those which enable us to regulate our digestion. The fibres which conduct messages outward are called efferent fibres. Most of them cause muscles to contract, and are called motor fibres. But some go to glands and other immobile organs, or make muscles relax. Most nerves contain both afferent and efferent fibres, but a few, such as the nerves from the eye and ear, are one-way streets. A large nerve, such as that from the eye, may consist of about half a million fibres.

Each fibre is a tube full of a sticky fluid, and is part of a cell whose nucleus is inside the central nervous system, or in a ganglion outside it. If a nerve is cut, the parts of the fibre separated from the nucleus die in two or three days. The messages which pass along the fibre are series of "impulses" like "dots" in Morse code. They travel at a speed varying in different fibres from about 250 miles per hour down to under sixty. Each impulse is a wave of chemical charge accompanied by a small electrical disturbance giving a potential of about a twentieth of a volt, which can be amplified with radio valves, and made to work a loudspeaker or a recording pen.

Each nervous impulse is as powerful as the fibre can manage. There are not different kinds in one fibre, like dots and dashes. Nor are they essentially different in different fibres. Whether a series of impulses along a fibre will give rise to a sensation of sight, touch or pain, to a movement, to a secretion of tears, sweat or a digestive juice, depends on the connections of the fibre, and not on the quality of the impulses.

The impulses going inwards start from what are called receptor organs, each specialised to respond most readily to a particular kind of physical or chemical process, and often provided with apparatus to magnify the process in question. But they can also be stimulated by other processes. For example, the receptor cells in the retina at the back of the eye are particularly sensitive to light, and the eye is so arranged as to concentrate light on them. But they can easily be stimulated by gentle pressure with a finger tip, or by a weak electric current. The more strongly the receptor organ at the end of a fibre is stimulated, the more frequently it sends impulses along the fibre. The frequency may vary from about a hundred to less than one per second. But all the information which we get from our senses has to pass through this bottleneck of series of impulses along nerve fibres; and one of the great problems of philosophy has been to understand how, if this is so, we can know anything about things.

In the same way, when we move a limb voluntarily, an immensely complicated series of volleys of nervous impulses goes out along tens of thousands of nerve fibres to the muscles concerned. Each fibre makes contact with a muscle fibre, and each impulse lets loose a small quantity of a substance called acetyl-choline, which causes the fibre to contract.

A series of impulses from receptor organs may give rise to a response by effectors. This may be an unconscious reflex action like breathing, speeding up the heart, or sweating; a fully voluntary action, like skilled work or speech; or something in between, like ordinary walking. But in any case the impulses have to pass through the central nervous system. This is a collection of several thousand million nerve cells, each connected with a number of others by microscopic nerve fibres.

We can get an idea of its complexity by imagining a telephone exchange in which every member of the human race was an operator, each sitting at a switchboard where he or she could call up a fairly small number of other operators. But the messages would be in a very simple code, nothing so complicated as speech. Unfortunately we can only see the individual operators, or neurones, as they are called, after they are dead. And though it is possible to tap a single nerve fibre under the skin, we cannot yet listen in to a single operator in the brain, though we can observe the electrical disturbances produced by a large number. We know that there are a few million operators at the end of afferent nerve fibres, such as those from the eyes and skin, and a smaller number, less than a million, sending out messages along efferent fibres. The vast majority are in between them in the network of nerve fibres. A century of careful work has only taught us the rough outlines of their organisation.

We know, for example, from a study of brain injuries, that no amount of activity of the neurones immediately connected with sensory nerves will cause the faintest sensation. Before there is any sensation these neurones must "call up" a number of others, and these must pass the message on still further. We also know something about the principles according to which the different parts of the nervous system interact. They are not easy to understand, but they have a dialectic of their own which a Marxist should find easy to grasp.

THE DIALECTICS OF THE NERVOUS SYSTEM

WHAT HAPPENS WHEN WE MAKE A RAPID MOVEMENT, such as straightening the elbow joint during a blow in boxing? The most obvious thing is contraction of a muscle, in this case the triceps running from the shoulder to the outside of the elbow.

But this is not all. If it were, the movement would end with a violent jerk which would strain the elbow and perhaps break a bone. Throughout the straightening process the biceps muscle whose contraction bends the elbow is gradually relaxing, but never so completely as to make the movement jerky. Even when we are at rest, all our muscles are in a state of slight contraction. Impulses are coming to them from the spinal cord, or in the case of the head and some internal organs, directly from the brain. In any movement the slackening of the tension in one set of muscles is almost as important as the increase of tension in another set. Thus posture and movement are achieved by a unity of opposite processes. We do not have to think or will in order to achieve this reciprocal innervation of antagonistic muscles, as Sherrington called this process. On the contrary, it occurs in reflex as well as voluntary actions, and the sets of neurones, or nerve cells, responsible for it, are mostly in the spinal cord.

This process may go wrong. Our lower jaw has a very powerful muscle to shut it, and a weaker one to open it. When we want to open it we not only contract the weak one but relax the strong one. However, in tetanus, strychnine poisoning, and some other conditions, the mechanism goes wrong. The nervous impulses which should inhibit the neurones which are signalling to the jaw-shutting muscle do not do so: they make them more active than before. The more one desires to open one's mouth, the more tightly one shuts it. Both the opening and shutting muscles are pulling against one another. The latter is the stronger, and wins. That is why tetanus is called lockjaw.

Every war leaves a number of unfortunate men and women whose nervous systems have been divided, so that one can study what one part does without the other. If the spinal cord is divided in the middle of the back, the legs and belly are insensitive and cannot be moved voluntarily. No messages run between them and the brain. But the severed part of the spinal cord can carry out reflexes. If one scratches such a man's foot it is pulled up, though he knows nothing about it. Perhaps the most familiar reflex carried out by the spinal cord is the scratch reflex which one can get in most dogs by tickling their back or flanks. The hind leg moves rapidly but seldom reaches the exact site of the tickling.

In the same way the lower parts of the brain can carry on such activities as breathing, swallowing, and temperature control when the upper parts are out of action. By a careful study of the effects of injury and disease one can determine the functions of the higher centres, which are more developed in man than in other animals. The result is at first sight surprising. One might expect that when a part of the brain was destroyed a group of muscles would cease to act. This may happen, but they may become over-active. In some forms of paralysis the leg muscles are permanently contracted in the standing posture. In fact the ordinary reflex involved in standing has got out of control. In other diseases of the brain the patient cannot keep still. Indeed a moderate tremor of the hands is quite common in old people.

Where the higher parts of the brain are working properly they can do one of three things: They can inhibit the reflexes which the lower parts would otherwise carry out; they can let them go on under control; or, finally, they can set muscular movements going without reference to the lower levels. But even then much of the "staff work", for example, the loosening of one muscle in the arm as another tightens, is done quite unconsciously by groups of nerve cells in the spinal cord. A great deal of our normal activity is simply the guiding of reflex actions by the upper parts of the brain. If you are just tickling your dog, he lets the scratch reflex look after itself. If a flea worries him, he takes control of it and scratches accurately. If you are walking on flat ground, you do not think about it; each step is a reflex in response to nervous impulses from your legs and feet of which you are unconscious. But on very rough ground you take conscious control of these reflexes, The relations between the different parts of the brain, of whose activity we are conscious, is very similar. The surface of the brain can be stimulated electrically in a fully conscious man. This causes various sensations and involuntary movements, but it never causes pain. The parts of the brain concerned with pain and the more primitive emotions such as rage are well below the surface. A large part of right conduct consists in inhibiting the activities of these parts when desirable, and in letting them go when desirable. We often have to control our sexual emotions, but there are times when we quite rightly give them their head. Otherwise the human race would come to an end. We often have to suppress rage, but controlled anger is a most potent weapon against injustice.

The relations between the different conscious parts of our brain is not fundamentally different from that between a conscious and an unconscious part, as, for instance, when a swimmer or a singer controls his breathing. It is a general rule that so long as reflexes go on smoothly we are not conscious of them. As soon as there is any conflict we become conscious and exercise a choice. For example, we chew and swallow automatically till we come on a hard lump or a fishbone which requires special action. Even highly skilled work becomes automatic with practice. Consciousness and will are switched on when anything goes wrong with the routine. We can only begin to understand our nervous systems if we realise that a certain amount of struggle between its different parts is not only usual, but absolutely normal and necessary.

SEEING

WE CAN GET SOME IDEA OF HOW THE SENSE ORGANS work from a study of the eye. We probably know more about the eye than any other organ in the body, because it is the only organ at whose working parts we can look without a surgical operation.

So far as its optical arrangements go, it is not unlike a photographic camera. The cornea, the transparent window which bulges out at the front, does most of the focusing. However, the adjustment for changes of distance is made by the lens which lies behind the iris, as the brown or blue ring around the pupil is called. Man and other mammals, and also birds and many reptiles, alter their focus by squeezing the lens, which is made of an elastic gristly material, into a different shape. But fish do so by pulling their lens backwards and forwards. It would be interesting to know whether the designers of the first cameras had taken hints from the study of fish eyes.

The most striking differences from a camera are that the sensitive film, instead of being flat, is concave towards the light, and that even a single eye can see over a far wider field than most cameras can photograph.

As an optical instrument, the eye has many defects as compared with a good camera. But it has two overwhelming advantages: it can repair small injuries; and its sensitive film will not only last for a century if need be, but can be adapted to different intensities of light. One reason for this is very simple. Men have known a little optics for several thousand years, and a great deal for 250 years. Chemistry was only put on a rational basis by Dalton a little over a century ago, and we are only just beginning to understand the chemistry of photography. A hundred years hence it may be possible to use the same plate a million times, and to use it for snapshots in gaslight and starlight. This is how we do actually use the retina, the sensitive film at the back of each eye.

Each retina consists of millions of sensitive cells and nerve cells linked up with them. There are two kinds of sensitive cell, the cones which serve for the coloured vision of ordinary life, and the rods which are used for the colourless vision of almost complete darkness. There are about ten thousand cones in a square millimetre of retina, and this sets a limit to the smallness of objects we can distinguish. If the images of two bright points fall on the same cone, we cannot distinguish them however good the focusing.

Now if we were trying to make a model of the eye, our sensitive screen would consist of many thousands of photo-electric cells, each producing a current along a particular wire when illuminated. In this way we could transmit a series of pictures to a distance, though it would be a very cumbrous apparatus. But that is not how a sense organ works. The activity of each part depends not only on the light falling on it, but on what has happened to it in the past, and on what its neighbours are doing.

This behaviour is quite characteristic of sense organs. Everyone knows that if one puts the right hand in hot water and the left in cold water for a few minutes, and then puts both in lukewarm water, it will feel cold to the right hand and hot to the left.

One cannot do this with the eye, because the different parts of the retina influence one another. But one can take two men, one of whom has been in a coal mine and the other in bright sunlight, into the same dimly lighted room. The miner will be almost dazzled, the man from sunlight will hardly be able to see.

The different parts of the retina influence one another. The same piece of grey paper appears white on a black ground and almost black on a white one. And white seems yellowish on a blue ground, but bluish on a yellow one. Careful experiments have shown that the processes which lead to such contrasting effects take place largely in the retina, and not in the brain. For it is possible to place an electrode on the eye, and to measure the electrical potential produced by the retina when a light is turned on or off.

In fact our sense organs are adapted for the purposes of ordinary life rather than for scientific observations. The eye exaggerates differences of hue or intensity in such a way as to help us to pick things out from their background. With the number of nerve fibres available only a certain number of messages can be sent per second. It is much more useful to be able to distinguish slight differences of light intensity than to measure absolute intensities. The latter would only be useful if we always lived in rooms with the same illumination and no shadows.

Our other sense organs behave in much the same way. After half an hour in an almost completely soundproof room one hears the sound of one's own heart very distinctly. And one soon gets accustomed to the most intense smells, or sewermen would go mad. As a consequence, the senses tell us about matter in relation to us rather than about matter as such. This is why the scientific account of the world is at first sight so strange. A thermometer gives a better estimate of the temperature of water than our fingers because it is little affected by its own past, and not at all by other thermometers. This does not mean that we must distrust our senses. We have no other source of information about the world. It means that we must realise that our sense organs are not machines: in fact they are better than machines in some ways and worse in others.

It also means that each sense organ can be used best for any particular purpose under certain conditions. Different classes of work demand different illuminations. A night fighter pilot must start off "dark adapted", so he must wear dark glasses until he starts off. A compositor needs a strong light.

A better knowledge of the physiology of our sense organs would not only help us to understand the world better. It would save us a vast amount of fatigue and accidents.

THE SENSES OF THE SKIN

WE USUALLY SPEAK OF FIVE SENSES, NAMELY SIGHT, hearing, taste, smell, and touch. This list goes back to Aristotle, and is badly out of date.

The work of physiologists during the last hundred years shows that the skin alone is responsible for at least five distinct kinds of sensation, namely touch, pressure, cold, heat, and pain. Besides these the internal ear originates sensations which tell us which way up we are, whether we are rising or falling, and whether we are turning round. The muscles, tendons, and joints give us sensations about our movements and postures. This last class of sensations do not bulk very large in our consciousness, but they are immensely important for skilled work. If the muscle sensations are lost through disease or injury, one cannot do fine movements, even though the skin sensations remain, and the muscles can exert as great force as before.

Marx particularly stressed that we learn about the world by acting on it. In this sort of learning the muscular sense is, of course, very important. However, it is hard to investigate, because the sensory organs lie deep in our limbs and trunk, so it is difficult to find out, for example, the relative importance of muscles, tendons, and joints in perceiving movement.

But it is quite possible to stimulate a small area of skin, report the sensations caused, and then, if desired, to cut it out, stain it, and examine it with a microscope to see what kinds of sense organs and nerve fibres it contains. Two British anatomists, Woollard and Weddell, have done important work on these lines in recent years. The skin of our fingers is richly supplied with nerve fibres and sense organs, and generally gives us rather detailed and rich sensations. But other areas, such as the thigh, have a much poorer set of sense organs. It is easy to find spots on the thigh which will give sensations of warmth only, or cold only, and not very hard to find areas which are insensitive to light touch. The temperature sense is perhaps the easiest to investigate. The organs giving rise to the sensation of warmth, called the organs of Ruffini after the man who first described them but did not discover their function, are only stimulated by heat. The corresponding organs for cold, the bulbs of Krause, lie nearer the surface, and are set off by cold or great heat.

The result is curious. If one puts one's finger into very hot water one may feel a sensation of cold before one feels warmth. And as the temperature of water increases, one notices first the sensation of warmth, which is a pure one, then heat, which is a mixture of the cold and warm sensations. Later on pain becomes noticeable, until it finally masks the other feelings. That is what happens when a large area of skin is heated. But if one stimulates an isolated cold spot with a thin hot metal rod one may get sensations of cold without any feeling of warmth.

There are at least three different sets of sense organs for touch, those called Meissner's corpuscles and Merkel's discs near the surface, and also organs round the hair roots which tell us when the hairs are bent. And fairly deep under the skin are the Pacinian corpuscles which give sensations of pressure. They are the largest of the skin sense organs, but are only a millimetre long. By injecting cocaine into the skin, by cooling it, and by other similar means, it is possible to deaden the sensibility of one set of organs and not another, and thus to demonstrate how complicated is our sense of touch.

Finally there are two sets of nerve endings whose stimulation causes pain, one close to the surface, and responsible for "fast pain", another deeper one which is not so rapidly excited. Pain is certainly a special kind of sensation, and not necessarily unpleasant in small doses, as everyone knows who has taken a long walk or played a game of football.

Several different nerve fibres are connected to one group of end organs, for example, a cold spot or a net round a hair root, and one nerve fibre usually branches and supplies several end organs. As a result we get a fairly fine discrimination of the place and intensity of sensation. When a nerve has been cut or crushed there is no feeling in the skin supplied by it for some weeks or months. When it grows again, the supply of nerve fibres to the skin is at first low. So each fibre has to serve a considerable area of skin without any overlap between the areas served by different fibres. Consequently, although one knows that the skin is being touched one cannot put one's finger on the exact place. Also since each sense organ is served by only one fibre the sensation is not graded, and is of a harsh and unpleasant character. This remains for life if the nerve does not regenerate properly. I have two skin areas with this type of sensation, one where a nerve in my arm was cut by a shell splinter in 1915, and one where a nerve to my back was damaged during a diving experiment in 1940. Hundreds of thousands of other wounded men have similar areas.

The messages along the nerves from the various sense organs in the skin, of which there are probably the best part of a million, are sorted out and relayed in the central part of the nervous system, and these processes may go wrong. So may their interpretation in the brain. For example, a man with a brain injury from a shell or bomb splinter in the region concerned with hand sensation may be as sensitive as ever to light touch, and even as capable as before of telling whether he is touched at one or two places. But he may be unable to tell a penny from a matchbox held in his hand.

In consequence a careful study of skin sensation can tell a great deal about injuries both to the nerves and to the spinal cord or brain, and may give a surgeon indications as to where to operate. It is interesting to note that it was employed for another purpose in the Middle Ages. If a spot could be found on a woman where she felt no pain she was liable to be burned as a witch. We know that a number of the people so killed in England were sufferers from nervous diseases which made them produce such contortions and grimaces that they were believed to be possessed by the devil. One of the pedigrees of Huntington's chorea in the United States has been traced back to a woman burned as a witch in Suffolk in the sixteenth century.

Mr. C. S. Lewis is now trying to revive the belief in witch-craft and demoniacal possession. If he succeeds, perhaps we shall start such practices again. They would be a pleasing accompaniment of a British brand of fascism, no more cruel or irrational than things which were being done in Germany a few years ago.

We must always be on guard against revivals of superstition. Even a knowledge of the nerve endings in the skin may be needed as a weapon against such a revival.

HORMONES

I SUPPOSE MORE NONSENSE IS WRITTEN ABOUT HORMONES and the glands which make them than about any other branch of physiology. A hormone is a substance produced by one organ of the body, and regulating the activity of another part or parts. Some of the hormones, such as adrenaline, are fairly simple chemical substances, and can be made synthetically. Others are very complicated, and though they have been got fairly pure, we do not know their exact composition, much less how to make them.

All the hormones are needed for complete health, but so far as we know only two or three are absolutely essential for life. Besides producing ferments for digestion, our pancreas or sweet-bread makes a protein called insulin without which we cannot use sugar. In its absence the kidneys rapidly get rid of the unwanted sugar in our blood, and we waste away with diabetes. Too much insulin is even more fatal than too little. If we inject an overdose into a man, the liver takes up the sugar in his blood, the brain goes short, and after feeling extremely hungry, he dies in convulsions. Probably every cell in the body needs insulin, but it is so important to have just the right amount that it pays us to have it made in one place, under the control of the nervous system.

Another essential hormone is that of the parathyroid glands in the neck, which controls the amount of lime in the blood. With too little, the lime falls, and we get peculiar muscular spasms. Apparently the bones take the lime out of the blood. With too much, the bones begin to dissolve and the blood lime rises. Either can be fatal.

The outer parts of the adrenal glands situated near the kidneys secrete several hormones. One of them controls the movements of salt in our bodies as insulin controls that of sugar. A man in whom it is not being produced can sometimes be kept alive if given an ounce or more of salt per day. Otherwise he dies.

The thyroid gland in the neck produces a hormone called thyroxine which increases the rate of oxidation in the body above what would otherwise be the basal level. Without it one becomes fat, sluggish, and more or less idiotic. With too much one becomes thin and jumpy, with rapid pulse and other symptoms, and may die. A simple experiment shows how accurately the activity of this gland is regulated. Occasionally a man's thyroid gland has to be removed for cancer or some other reason. We know how much of the hormone he must be given every day to keep him in health. We can give this amount, or anything less, to an ordinary healthy man, and nothing whatever happens. His thyroid gland simply stops putting thyroxine into his blood, and the level is unaltered. But if we give him much more than the standard daily dose, his oxygen consumption when at rest goes up, and he is quite ill at the end of a fortnight.

The testicles in men, and the ovaries in women, produce hormones which are responsible for most of the changes such as the growth of the beard and of the breasts, which occur at puberty. A second female hormone, progesterone, is produced right through pregnancy, and for a part of each monthly cycle.

The organ which produces more hormones than any other is the pituitary gland lying in a little hollow in the skull under the brain. Its products regulate, among other things, growth, sugar utilisation, the secretion of milk, and the activity of the thyroid, adrenals, ovaries, and testicles. These latter organs grow larger and become functional at puberty because they are stimulated by one of the hormones from the pituitary. The production of this hormone in turn is delicately regulated.

If one thinks mechanistically about the body it is natural to suppose that by injecting testosterone, the testicular hormone, into a male animal, one could make him more virile, as one can certainly make a castrated animal grow and behave like a normal male by injecting it. But the effect is the opposite. The pituitary regulates its output of the gonad-stimulating hormone so as to keep the level of testosterone in the blood steady. If it is artificially raised above the standard level, the pituitary shuts down, and instead of the male becoming more virile, he becomes sterile.

In a similar way another of the pituitary hormones concerned in growth acts as an antagonist to insulin, and one which controls the thyroid gland is shut off by an excess of thyroxine. The more we learn about ourselves the more we find that the stability of any structure or function is due to the balance between two opposing processes. In fact every physiologist has to think dialectically about his own subject, however undialectically he may think about politics or economics. And although we now know a lot about the hormones, we merely make people ill if we try to use them mechanistically. I have no doubt that in future they will be very important in medicine, but we shall have to find out exactly how much to use in each particular case. Only a few of them, notably insulin and thyroxine, are of any great medical value so far, and a good deal of "hormone therapy" is useless or dangerous as well as expensive.

Some hormones have a very rapid action, and their production is switched on and off quickly. One such is adrenaline, produced by the central part of the adrenal gland during emotion and exercise. It stimulates the heart, and helps to switch the blood into the muscles where it is needed. Another hormone makes one sleepy, and is probably concerned in normal sleep. But most of them take some hours or even days to act.

To sum up, the hormones are important agents in linking up the activities of different organs, so that our bodies work as a whole. But any attempt to use them like so much lubricating oil, as if our bodies were mere machines, is as likely to kill us as to cure us.

GROWTH

SO FAR I HAVE WRITTEN NOTHING ABOUT GROWTH. This is an extremely fascinating story, because the whole development of a human being from a single cell to an adult depends on the different growth rates of different parts. For example, when you were about three months old, that is to say six months before you were born, you had no arms or legs, though you had a head, a body, and a tail. Then the cells at four points on your trunk began to divide quicker than their neighbours, and your limbs appeared as buds. Later on the growth of your tail slowed down, and it was finally covered up by the haunches. It is still there, as one can see on examining a skeleton. Since you were born your head has not grown a great deal. Your trunk has grown considerably more, and your arms and legs more again. If all the parts of a baby grew equally it would develop into a monster with a huge head and stumpy limbs.

But things are different in other animals. A calf or a foal has longer legs, relative to its body, than a cow or a horse. This means that its legs grow more slowly than its trunk. It is easy to see that this is an advantage to an animal which has to run when a few days old. The puzzle is to find out how the advantage is achieved.

If you are adult, the cells are only dividing in a few parts of you. Your skin, including the hair and nails, is constantly being made afresh. So are the linings of internal organs such as the bowels. And so are the cells in the blood. It might be thought that other parts had lost the power of growth. But this is not so. You can heal a cut, not only in your skin, but in most internal organs. Broken bones will mend, though not quite so quickly in adults as in young children.

You may form a wart, either on the skin or inside you. Finally some group of cells may start unrestricted growth, and begin to migrate into other organs. Unless they can all be removed by the surgeon or killed with X-rays or radium, this means that you will die of cancer. The problem of cancer will be much nearer solution when we find out why most cells stop growing when they do, and how growth is regulated so that each part of a baby grows at such a rate as to produce the normal adult form. We know a little about this, partly from experiments on eggs of frogs, newts, and other animals in which it is easy to interfere with the normal process. We know, for example, that some of the cells of the embryonic skin transform themselves into a nervous system because of chemical substances produced by the underlying organs. If certain substances are injected under the skin of a developing newt's egg, it will develop two nervous systems. We also know that the rapid multiplication of cells which occurs when a wound is healing is due in part at least to chemical substances produced by cells which have died in the neighbourhood of the wound. It is not controlled by the nervous system, for wounds heal in a limb whose nerves have been cut. At the present time I am working on one little corner of this problem, namely, how best to calculate the relative growth rates of two organs, say the hind leg and body of a calf, from a series of measurements.

Unfortunately the only people who study human physiology systematically are medical students, and all the books on it are written for them. I believe that everyone should learn some human anatomy and physiology for several reasons. First of all, because without it we cannot understand first aid or hygiene, of which everyone should know something. Secondly, because it is the most obvious approach to biology. Why should children study trees and insects before they have studied themselves?

Thirdly, this knowledge is apt to be a monopoly of the medical profession, and monopoly in knowledge is as bad as monopoly in production. I have great confidence in medicine, but I certainly do not want to see doctors usurping the place in society which was occupied by priests in the Middle Ages. And the attitude of some doctors towards the public health service reminds me a little too strongly of the attitude of the clergy six hundred years ago.

Fourthly, we all have to learn about the physiology of reproduction when we grow up. Much of what we learn is superstition, and dirty superstition at that. Special school lessons on this subject are unsatisfactory. But we can learn it as part of a general study of our bodies and minds. A baby's growth before and after it is born are part of the same process. We ought to be able to discuss one as easily as the other, and above all to take as much care of a baby before its birth as afterwards.

Finally, the study of ourselves is a valuable introduction to a philosophical view of science. Hardly anyone really believes that he or she is a machine. Yet there is a sense in which we are machines, and an equally important one in which we are not. The French materialists of the eighteenth century, such as Diderot and La Mettrie, were quite correct in many of their statements, indeed in some ways we are even more machines than they realised. But they took a very one-sided view of many questions. Hegel, and most academic philosophers, went too far the other way. Marx and his colleague Engels tried to combine what was true in the mechanistic and idealistic views. And although their philosophy is based on the science of eighty years ago, and therefore needs to be brought up to date in places, it is still an immensely valuable guide to the understanding of sciences, particularly of those which deal with life.

WHAT IS LIFE?

I AM NOT GOING TO ANSWER THIS QUESTION. IN FACT, I doubt if it will ever be possible to give a full answer, because we know what it feels like to be alive, just as we know what redness, or pain, or effort are. So we cannot describe them in terms of anything else. But it is not a foolish question to ask, because we often want to know whether a man is alive or not, and when we are dealing with the microscopic agents of disease, it is clear enough that bacteria are alive, but far from clear whether viruses, such as those which cause measles and smallpox, are so.

So we have to try to describe life in terms of something else, even if the description is quite incomplete. We might try some such expression as "the influence of spirit on matter". But this would be of little use for several reasons. For one thing, even if you are sure that man, and even dogs, have spirits, it needs a lot of faith to find a spirit in an oyster or a potato. For another thing, such a definition would certainly cover great works of art, or books which clearly show their author's mind, and go on influencing readers long after he is dead. Similarly, it is no good trying to define life in terms of a life force. George Bernard Shaw and Professor C. E. M. Joad think there is a life force in living things. But if this has any meaning, which I doubt, you can only detect the life force in an animal or plant by its effects on matter. So we should have to define life in terms of matter. In ordinary life we recognise living things partly by their shape and texture. But these do not change for some hours after death. In the case of mammals and birds we are sure they are dead if they are cold.

This test will not work on a frog or a snail. We take it that they are dead if they will not move when touched. But in the case of a plant the only obvious test is whether it will grow, and this may take months to find out. All these tests agree in using some kind of motion or change as the criterion of life, for heat is only irregular motion of atoms. They also agree in being physical rather than chemical tests. There is no doubt, I think, that we can learn a lot more about life from a chemical than from a physical approach. This does not mean that life has been fully explained in terms of chemistry. It does mean that it is a pattern of chemical rather than physical events. Perhaps I can make this clear by an example.

Suppose a blind man and a deaf man both go to performances of *Macbeth* and of *Alexander Nevsky*. The deaf man will understand little of the play. He will not know Duncan was murdered, let alone who did it. The blind man will miss far less. The essential part of Shakespeare's plays are the words. But with the film it will be the other way round.

What is common to all life is the chemical events. And these are extraordinarily similar in very different organisms. We may say that life is essentially a pattern of chemical happenings, and that in addition there is some building of a characteristic shape in almost all living things, characteristic motion in most animals, and feeling and purpose in some of them. The chemical make-up of different living things is very different. A tree consists largely of wood, which is not very like any of the constituents of a man, though rather like a stuff called glycogen which is part of most, if not all, of our organs. But the chemical changes which go on in the leaves, bark, and roots of a tree, particularly the roots, are surprisingly like those which go on in human organs. The roots need oxygen just as a man does, and you can see whether a root is alive, just as you can see whether a dog is alive, by measuring the amount of oxygen which it consumes per minute. And the oxygen is used in the same kinds of chemical processes, which may roughly be described as controlled burning of foodstuffs at a low temperature. Under ordinary circumstances oxygen does not combine with sugar unless both are heated. It does so in almost all living things through the agency of what are called enzymes. Most of the oxygen which we use has first to unite with an enzyme consisting mainly of protein, but containing a little iron. Warburg discovered this in yeast in 1924. In 1926 I did some rather rough experiments which showed the same, or very nearly the same, enzyme in green plants, moths, and rats. Since then it has been found in a great variety of living things.

Just the same is true for other processes. A potato makes sugar into starch and your liver makes it into glycogen by substantially the same process. Most of the steps by which sugar is broken down in alcoholic fermentation and muscular contraction are the same. And so on. The end results of these processes are, of course, very different. A factory may switch over from making bren guns to making sewing machines or bicycles without very great changes. Similarly the chemical processes by which an insect makes its skin and a snail its slime are very similar, though the products differ greatly.

In fact, all life is characterised by a fundamentally similar set of chemical processes arranged in very different patterns. Thus, animals use up foodstuffs, while most plants make them. But in both plants and animals the building up and breaking down are both going on all the time. The balance is different.

Engels said that life was the mode of existence of proteins (the word which he used is often translated as "albuminous substances"). This is true in so far as all enzymes seem to be proteins. And it is true in so far as the fundamental similarity of all living things is a chemical one. But enzymes and other proteins can be purified and will carry on their characteristic activities in glass bottles. And no biochemist would say they were alive.

In the same way Shakespeare's plays consist of words, whereas words are a very small part of Eisenstein's films. It is important to know this, as it is important to know that life consists of chemical processes. But the arrangement of the words is even more important than the words themselves. And in the same way life is a pattern of chemical processes.

This pattern has special properties. It begets a similar pattern, as a flame does, but it regulates itself as a flame does not except to a slight extent. And, of course, it has many other peculiarities. So when we have said that life is a pattern of chemical processes, we have said something true and important. It is practically important because we are at last learning how to control some of them, and the first fruits of this knowledge are practical inventions like the use of sulphonamides, penicillin, and streptomycin.

But to suppose that one can describe life fully on these lines is to attempt to reduce it to mechanism, which I believe to be impossible. On the other hand, to say that life does not consist of chemical processes is to my mind as futile and untrue as to say that poetry does not consist of words.

PART II

HEREDITY AND ENVIRONMENT

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EUGENICS

I AM CONSTANTLY BEING ATTACKED FROM TWO SIDES for my statements on the question of eugenics, and still more for statements which I am alleged to have made. So I think it is worth while stating my own views, if only as a basis for discussion.

Extreme "eugenists" say that since it is known that some people start life with a hereditary handicap, every possible step should be taken to prevent more such people being born, and any opposition to such steps is either mere sentimentalism, or perhaps the result of orders from Moscow. Others say that any recognition of inherited differences between human beings labels me as a fascist. Once you admit that there are such differences, I am told, you justify Hitler's policy against the Jews, Poles, and Ukrainians, not to mention the numerous Germans who were murdered in the name of racial hygiene.

Now let us take a concrete case. About one male baby in ten thousand is born with haemophilia, a condition in which the blood will not clot. Haemophilics usually bleed to death, and their average length of life is eighteen years. No cure is known, though various treatments can check bleeding to some extent. The disease is very strongly inherited. The children of haemophilics are normal, and the sons do not transmit it; but if we count sufficient numbers, half the sons of haemophilics' daughters are haemophilics, and half the daughters' daughters pass it on in the same way. The condition would in time be abolished by natural selection if it did not keep on recurring from unknown causes. Each recurrence can start a new pedigree of the disease. It is no good saying that its occurrence is due to bad conditions, since it occurs in all social classes, including royalty. If it is due to bad conditions, no one knows what they are. I would agree with negative eugenists that haemophilics should not have children, and I think their daughters should probably not have them either. But that does not mean that I think they or their daughters ought to be sterilised. (For one thing, such an operation would often kill a haemophilic.)

Once you make sterilisation legal for one reason it is likely to be used for others, for example, on people whom the Government regards as mentally or morally subnormal. I think it is far more dangerous to the community that children should be brought up with a bias towards being financiers than that they should be born with a bias towards mental defect. I am not in favour of sterilising either defectives or financiers, but if I had to choose it would be the financiers who would first be deprived of opportunities to reproduce.

I know that as a matter of fact people with serious hereditary diseases do abstain from parenthood to a very large extent when the facts are explained to them, and the more people understand these facts the more will this be so. In fact, education will do a very great deal do cut down the transmission of such diseases.

"But what about mental defect?" I am asked. "Surely we should sterilise mental defectives, as we can't educate them not to have children." I don't agree. I don't think mental defectives should have children. This is not because mental defect is strongly inherited. It is not. Of 345 Birmingham children one or both of whose parents were defectives, only seven and a half per cent. were at special schools or reported for special school examination. Another eighteen and a half per cent. were backward. A few were even above the average. An equally important reason is that a mentally defective mother or father cannot bring children up properly; though I would sooner see children reared by a decent mental defective than by a mother who taught them to be shoplifters or prostitutes.

Many mental defectives are well looked after by their families, and can do unskilled work, so that they are no great burden on the community. Where this is not possible they should be sent to institutions, in some of which at least they are quite well treated. No one who can do steady and useful work should be classed as a mental defective, even if he or she cannot read. Anyone who cannot work had better be taken off the labour market until we have got rid of unemployment for good. When that time comes, and there are so many jobs that we even need defectives to do them, it will be time to talk about letting them out and sterilising them.

I hope, however, that the example of the Nazis will be enough to keep us from adopting this practice for at least a generation to come. By that time Britain will, I hope, be a socialist country, and those who are studying the question will have found out a great deal more about the origin of mental defect. It seems quite likely that some kinds only arise when a particular type of man has children by a particular type of woman. If this turns out to be true, future parliaments may think it right to forbid such unions, as we forbid those of brothers and sisters.

I am definitely in favour of eugenics when two conditions are fulfilled. One is that we should know a great deal more than we yet do about human heredity. The other is that class distinctions should have been abolished, so that eugenics cannot be used as an excuse for persecuting people of whom the ruling class disapproves. I am quite convinced that there are inborn differences between human beings, for example, that no amount of education could have made me as musical as most of my readers. For I inherited a very "bad ear" from my mother. I also believe that at least nine people out of ten have enough inborn ability to be really good at some useful work or other. And I believe that these differences are determined by heredity, which does not mean necessarily handed down from parent to child.

A DISCUSSION AT PRINCETON

I WAS ONE OF FIVE BRITISH BIOLOGISTS INVITED BY Princeton University to a three days' discussion, which was a part of the celebration of the University's bicentenary. Its object was to bring together men who were studying evolution from two different angles. The palaeontologists study the changes which have taken place in time, for example, the differences between the bones and teeth of modern horses, asses, and zebras, and those of their ancestors in the Pliocene period before the great Ice Ages. The geneticists study the nature of the differences between different closely related animals and plants, for example, between fish in Mexican rivers which clearly belong to different species, and rarely hybridise in nature, but yet are near enough to give fertile hybrids in captivity, so that one can see how the differences between the species are determined.

One might compare the Princeton conference with a conference in which historians were brought together with students of contemporary economics and politics. But the comparison is not quite fair because we know a good deal about the economics of even two thousand years ago, for example, the prices of corn, copper, and slaves in terms of gold in ancient Rome. And we certainly do not know, though we can often guess, what were the selective advantages or disadvantages of a particular detail of tooth shape in horses or elephants ten million years ago.

Nevertheless such meetings are now more worth while than they were twenty years ago, for several reasons. The palæontologists have ample records of some species. They can say how much the teeth varied in a population of extinct horses all buried in the same quicksand, and whether the change in tooth form found in horses buried a million years later could have been due to selection of the variations in a particular direction. Darwin believed that they could, though he had practically no knowledge of variation in extinct animals. The evidence which we can now bring from the study of variation in fossils strongly supports Darwin's theory, though, of course, a very great deal more evidence is needed, just as we need more evidence to support or counter the Marxist explanation of change in prehistoric human societies.

The conference began with a review of the methods which have been used to date various rocks. By far the best evidence is from the amounts of lead formed by the transformation of the elements in radioactive minerals. The main difficulty is that radioactive rocks are generally igneous, formed by volcanoes or in the molten depths of the earth, while fossils are mostly found in sedimentary rocks, laid down by water. So only a few fossils are really accurately dated. However, we know that the age of great reptiles came to an end, and mammals became the dominant land animals, about seventy million years ago, whereas the earliest vertebrate fossils, of primitive jawless armoured fish, were formed a little over four hundred million years before our time; and some other dates, such as that at which our ancestors came out of the water, are also pretty well known.

One striking conclusion was the very uneven rate of development in different groups. Some shellfish have remained practically unaltered for four hundred million years, down to the details of the attachment of the muscles for closing and opening the shells, and pulling in parts which project outside them. In the same time the vertebrates have evolved from jawless fish to men, hoofed mammals, carnivores, birds, and all the huge range of vertebrate forms. Even such a relatively advanced animal as the opossum has stayed put for seventy million years. There is no inevitable law of progress. One cannot help thinking of the law of the uneven development of capitalism. But as there are many more families of animals than Capitalist States, the evidence is even more impressive.

Darwin called his great book *The Origin of Species.* But it is now clear that we have to explain two rather different processes. The first is a change in a whole population such as the increase in the length of the molar teeth of ancestral horses which enabled them to chew grass, a process which would have worn down their short-toothed tree-browsing ancestors' teeth in a year or so.

The other is the division of one ancestral species into two or more, such as wild horses, wild asses, and various kinds of zebra. These two processes are quite distinct. Probably a majority of the conference thought that a species never, or very rarely, splits up in the same habitat. Horses and zebras evolved from a common ancestor in different countries. Although there may be a good deal of variation in colour and structure between members of a species living together, this rarely seems to reach the stage of splitting a species in two. On the other hand quite a small geographical barrier, such as a valley between two mountain ranges, may cause a species to split into two new ones which after some thousands of years are unable to cross one with another. The Californian botanists are studying a number of plant species in the making, because in this part of the United States there are many fertile areas separated by desert since the Ice Ages, and big differences have arisen in the last twenty thousand years, whereas, except for a few mountain plants, this has not happened elsewhere in the United States within the same time.

On the other hand, the industrial areas of Europe offer the most striking examples of changes in populations in response to changed environments, notably the development of hereditary black varieties of moths in the black countries of England and Germany.

The geneticists stressed the belief that evolution could be explained in terms of known causes, and without any supernatural intervention. They also pointed out that evolution was the result of struggle, not merely a "struggle for life" between individuals, but a struggle between opposing processes, such as mutation which tends to make a species variable, and selection which reduces variability. In fact, some of them talked good dialectical materialism without knowing it.

We also saw extremely interesting specimens, including the fragmentary skulls of the giant apemen from Java and China. As few of their other bones are preserved we do not know their size exactly. But the fact that their skulls were an inch thick is sufficiently impressive. They were built for fighting rather than thinking. Probably the most valuable result of such a conference is the interchange of information and opinions on points of detail.

Thanks to the war, British and American people understand one another less than they did ten years ago. These misunderstandings may be disastrous to the world. A few hundred meetings where workers in different occupations met their opposite numbers would do much to bridge the gap. Now that the C.I.O., and the A.F.L., are coming together, fraternal relations between British and American unions should become easier, and I very much hope that other workers will get together, as scientific workers are beginning to do.

SEX EDUCATION

I HAVE HAD A NUMBER OF LETTERS ASKING MY VIEWS on how children should be taught the facts about human reproduction. I answer with great diffidence, because I have no practical experience of teaching children, though I lecture to university students on various topics connected with sex.

To my mind there are several things wrong with our attitude to this problem. Some of them arise from the fact that sexual relations are used as a means of exploitation. The exploitation may be gross and obvious, as in prostitution, or more or less veiled, as when a husband expects his wife to do a sixteen-hour day in the house, or a flapper vamps sweets from a young man. These will disappear to a large extent with socialism, provided that it includes complete economic equality of the sexes, as in the Soviet Union, and that the principle of the wage for the job applies to household work.

But that is not the whole story. In all kinds of human societies there is an emotional attitude to sexual relations which makes their rational discussion very difficult. They are generally mixed up with religion, but even where this is not so it is very hard to discuss them without being either sentimental or dirty. There is, however, one set of people who manage this to a considerable extent, namely professional biologists. Sex is only one of a number of biological functions, and not the most interesting one for most of us. We are as interested in a snail's peculiar method of storing sugar as in its peculiar habit of pushing a spike into its mate, in the secretion of a man's liver or thyroid gland as in those of his testicles. In our conversation we pass from one of these topics to another without difficulty, whether or not we are all of the same sex. In such an atmosphere it is at least more likely that one will discover what is right and what is wrong in human sexual relations than in an atmosphere of shame, joking, or sentimentalism.

Children can be got into the frame of mind by teaching them biology. But it must be a real biology, the study of living plants and animals, including man. School biology consists mainly of anatomy, along with experiments on plants. It could include a great deal of human physiology and anatomy. Obviously you cannot expect children to dissect a corpse, or to do experiments on one another involving careful chemical analysis or complicated electrical measurements.

But every secondary school should have a skeleton, and a model showing the more important organs of the body; and quite a number of experiments are easy. For example, one can demonstrate such reflex actions as the contraction of the pupil when a light is shone on it, and the increase of the pulse rate with exercise. It is a little harder, but quite interesting, to work out which muscles are concerned in various kinds of work, and to measure the force which they exert. In fact, you can accustom people to regard their bodies as things to be studied, like steam engines, French irregular verbs, or rivers.

The anatomy and physiology of human reproduction would fit naturally into such a course of study. It is most important that it should not be taught separately, and should not be kept till the end of the course as a special titbit. Similarly venereal diseases should be described along with other ailments. At some point an account would have to be given of intercourse, which, like eating, begins with voluntary acts, and ends in a reflex as involuntary as swallowing. It can then be pointed out that reflexes can be conditioned, and that the conditioning of sexual reflexes is a large part of sexual morality.

The biggest difficulty is that children must be taught these things before they are ready for marriage or even love-making. Practice and theory must be separated to some extent. But more can be done to unite them than many people think. A doctor of my acquaintance believes that women should know what to expect, and therefore took both his daughters in their teens to see a baby born. It was born under good hospital conditions, with an analgesic, that is to say a drug which damped down the mother's pain without making her unconscious. One of the girls alarmed her father considerably by her determination to have a baby herself as soon as possible. When she had one, you may be sure that she insisted on using the resources of science to the fullest extent to help the baby and herself, and was a good deal less frightened than many mothers.

Some people will say that education of this kind would undermine the basis of morality. The basis of morality is regard for your neighbours and yourself. You cannot act rightly unless you know what you are doing and what are the probable consequences of your acts. Others will say that if you take the mystery out of love you will lose its delight. On the contrary, I appreciate spring colours more, not less, because I know the chemical nature of the pigments which make young leaves yellower than mature ones. I should appreciate music better if I knew more musical theory. It is the same with love. But I do not suppose for a moment that such proposals as my own will be accepted in a hurry. Opposition to such a spread of knowledge is not only religious. As Milton put it, writing on divorce just 300 years ago. "The greatest burden in the world is superstition, not only of Ceremonies in the Church, but of imaginary and scarecrow sins at home."

However, I think that we ought to have some ideal before us in this matter, so that we can work towards it.

IS SEX NECESSARY?

WE TAKE SEX FOR GRANTED, BECAUSE MOST OF THE animals which we know best have two separate sexes. But a number of quite familiar animals, such as the snail and earthworm, are hermaphrodites, combining the two sexes. So, of course, are most plants. A few animal species such as stick insects and some woodlice, consist of females only.

Why are two sexes needed? It is perfectly true that in most animal species, including our own, the female cannot normally breed without the help of a male. But it is quite easy to get several species of insects, such as the silkworm moth, to breed without males. And it is fairly easy to get unfertilised frogs' eggs to develop by chemical or mechanical means, while one author claims to have produced young from virgin rabbits, though there is a case for suspending judgment till his work has been repeated. Anyway in the course of evolution many species have done away with the male sex or with the separation of the sexes, so one may fairly ask what is their value, and why are there generally two sexes in animals.

There are probably two different reasons. Inbreeding seems to be harmful to a great many kinds of living things. Darwin was the first to do accurate experiments on this matter. He compared the vigour of plants produced by cross-fertilisation and self-fertilisation, and found that the former were generally larger and healthier. This has been confirmed in a great many animals and plants. Sometimes inbreeding (whether by self-fertilisation or the union of close relatives) produces abnormality, slow growth, and sterility. This would be the case with human beings if incestuous unions were allowed.

It is generally said that the ancient Egyptian kings married their sisters. Actually they usually had several wives, some being unrelated and one being a half sister, that is to say a daughter of their father by a different mother. This was a far less serious matter than a union with a whole sister, since new "blood" was constantly brought into the royal family.

With some animals, such as mice and guinea pigs, mating of whole brothers and sisters can go on for thirty or more generations without any great harm. But even here there is almost always a great increase in vigour and fertility once an outcross is made. Prolonged inbreeding of this sort always leads to a very uniform population. For example, if one member of a line of inbred mice has brown hair with a white belt, all of them will resemble it in a high degree. So inbreeding can be and is used to fix any character in domestic animals which the breeder desires.

Outbreeding has also the great advantage that it allows the recombination of different desirable characters. For example, if one race of wheat is resistant to frost, and another to the mould called rust, the first cross between them will probably not combine these characters; but they will be combined in some of the progeny in the next generation.

Thus occasional outcrossing speeds up either artificial or natural selection. The American biologist, Wright, believes that evolution occurs most quickly when a species is divided up into a number of small groups, each usually breeding with itself, but occasionally crossing with another group. This enables many different combinations of characters to be tried, but gives a chance for exchange of characters between those types which succeed. Thus the division of a species into two sexes is useful because it allows recombination of this kind.

I have recently read several Nazi books on biology. They all appear to assume that racial mixture is a bad thing, and many of them state that the Germans should aim to become uniformly fair-haired, blue-eyed, tall, narrow-headed, and alike in all other respects. Such an ideal would, I think, be fatal to any people which realised it.

The importance of inborn characters has been greatly exaggerated. However, they do exist. I do not think that any amount of training would have made me a musician or a sprinter, though I have some inborn aptitude for mathematics and weight lifting. To meet the many different calls of life, it is surely desirable that a people should have a fair diversity of natural talents. If it had been the destiny of the Germans to order the rest of mankind about, as Hitler thought, there might have been some point in having them all alike. But fortunately they are not going to be a master race. They are going to have to work at a great many different jobs, and it will be a good thing if they are born with different aptitudes.

It may well be that different races, especially those whose ancestors have lived in one spot for ages, differ in their inborn abilities to a slight extent, each being adapted to its own way of life. This has been used as an argument against unions between different races. It is a bad argument, because modern men and women live in utterly new environments, and have to face new tasks. If the people of India are better capable than the British of standing great heat, a little Indian ancestry might be very useful for a British coal miner in any of our deeper pits.

No race has ever lived in an environment like a modern city, and perhaps different races may contribute different qualities needed in city dwellers.

We do not know enough about ourselves to answer such questions with anything like certainty, even on the biological, let alone the social, level. So far as concerns culture it certainly seems desirable that small nations, such as the Scottish, Irish, and Welsh, and even groups which cannot be called national, such as the Cornish, Manxmen, and Scottish Highlanders, should preserve their own traditions and ways of life, so far as they are compatible with modern methods of production. But it is also undesirable that any nation should shut itself off from the world, and inevitable and right that in a great city like London or Glasgow, men and women of many nations should mix. So far as can be seen at present, the same thing is desirable from a biological point of view.

THE EGG AND THE CHICKEN

ACCORDING TO "THE BRAINS TRUST BOOK", THE most frequently asked question was "Which came first, the chicken or the egg?" The fact that it is still asked proves either that many people have never been taught the theory of evolution, or that they don't believe it.

For the answer is quite clearly "The Egg". If by "chicken" you mean the young of our domestic poultry, poultry were descended from other birds which laid eggs, and, at whatever point you choose to draw the line, the first chicken came out of an egg, and this egg came out of something which was not quite a chicken. If by "chicken" you mean any young bird, then there is no serious doubt that birds are descended from egg-laying reptiles, and the answer is therefore the same. This is so even though, if we had specimens of all the ancestors of a living bird species, we probably should not know where to draw the line. The earliest bird-like animals whose fossils are known had teeth, long bony tails, and a line of flight feathers between their front and hind limbs. They probably glided like the Australian "flying" phalanger, and it is doubtful if they could fly in the ordinary sense of the word. So they may not deserve the name of birds.

Some reader may ask why I am so certain. The answer is that a scientific theory becomes certain in proportion to the number of times when an experiment or an observation might have disproved it, and has not done so. Now the theory of evolution consists of two parts. One part is the theory of descent, namely that existing animals are descended from ancestors unlike themselves, but that the changes in a single generation have never been very great. The second part of the theory deals with the causes of evolution; for example, Darwin thought (and I agree with him) that natural selection was the main cause. A great many lines of evolution are well established by the study of fossils. We have a very good genealogy of the horse, a fair one of man, and a very poor one of birds. Few birds get fossilised, as the acid soil produced by decaying leaves in a forest destroys bones; and most birds live, and probably lived, in forests. However, the broad lines of descent are so clear that evolution would at once be disproved if the skeleton of a man, a horse, or a bird were discovered imbedded in a coal seam. In case any practical joker wishes to claim that he has found one there, I may add that bones from the coal measures are impregnated with vegetable material, and a fake would at once be detected.

On the other hand it is not so certain how and why evolution occurred. A few able students of evolution think that natural selection was not the main force behind it, and adopt Lamarck's explanation or some other. Many more biologists suspend judgment. The situation in human history is much the same. It is quite certain that the English annexed the Gold Coast. Marxists think the reasons for this were economic, but they are prepared to argue with people who say the motive was a desire for glory, or a wish to spread civilisation or Christianity in Africa. It is no use arguing with a person who says that the Gold Coast is independent, or belongs to Brazil.

I have chosen a very simple example of a question which appeared insoluble before we had our present knowledge of evolution. Further advances in science will answer other questions which seem insoluble at present. For example, if the views on the evolution of the stars which Milne and I are propounding at present turn out to be right, a lot of ancient difficulties about time and space will vanish. But this theory will have to be checked, as the theory of evolution has been checked by a study of fossils. And the checking will take decades, or more probably centuries. The detailed consequences will have to be worked out, and astronomers will have to look for facts which would disprove the theory if it is wrong.

Engels, and also some non-socialist thinkers, such as W. K. Clifford, saw that evolution cleared up many more important problems than that of the egg and the chicken. For example, people still speak of eternal values, or eternal laws of morality. There is nothing eternal about the prohibition of stealing. Less than a million years ago our ancestors had nothing which could be called property. They did not store food, use tools, or wear clothes. In the remote future there may be no private property, either because all useful things will be made in such quantities that we shall no more want them for private use than we now want air or sunlight, or because the feeling of human brotherhood will be so strong that we shall take common ownership of everything as a matter of course.

Again evolution makes idealism much more difficult. If I were the only sentient being in the world there would be no way of deciding whether things were really there, or only in my mind. I am not sure if there would be any sense in the question. The fact that many people can see and feel the same mountain makes it much harder to believe that the mountain is nothing but an idea, a permanent possibility of sensation, or something of that kind.

But the theory of evolution and the geological record make it reasonably certain that there were mountains long before there were any animals, let alone human beings, to be aware of them, and Engels regarded this as one of the strongest arguments against idealism.

In fact, a belief in evolution should influence our thought on almost, if not quite all, subjects. Its importance for communists can be judged from two facts. Marx wanted to dedicate *Capital* to Darwin. Stalin was sacked from a theological seminary for reading Darwin's works.

THE ORIGIN OF THE VERTEBRATES

THE MAIN OUTLINES OF THE HISTORY OF THE EVOLUTION of vertebrate animals, including man, in the last four hundred million years, are now pretty clear. There are plenty of gaps to fill in.

We don't know the exact details of our own ancestry. The bones of a lot of animals whose form was roughly intermediate between those of a man and a gorilla have been found in Asia and Africa. Some of them used tools, so they can be classed as men. We do not yet know which of them, if any, were our ancestors. We shan't know until we have a lot more such fossils, and can trace slow changes in the form of the bones and teeth, as we can in the ancestors of modern horses, donkeys, and zebras.

There are still greater gaps in the remoter past. However, the following stages in human ancestry are quite clear. Four hundred million years ago our ancestors were fish (if you can call them fish) without lower jaws or paired fins. Then they developed jaws and fins. Later they came out of the water, but still waddled like newts without raising their bellies off the ground. After many million years they managed to stand up on four legs, but were still essentially reptiles. They next developed hair and started to bring forth their young alive. The fossil record does not enable us to say when they became warm-blooded or started suckling their young. In the last fifty million years they became expert climbers and their brains enlarged very notably. Several million years ago they lost their tails, and a million or so years ago they came down from the trees and started walking on their hind legs, and using their hands to hold things, and later to make tools.

But the ancestry of the first vertebrates was wrapped in mystery. There are two groups of living invertebrates which are somewhat like the vertebrates in their plan, though they look very unlike them. But a careful study of their anatomy and development shows the likeness, just as it shows that a snake is more closely related to a lizard, and an eel to a cod, than a snake or an eel are related to one another, though the outward shapes of a snake and an eel are similar.

One of these groups is the ascidians or sea-squirts. Most of them live attached to rocks in the sea, but some of them start life as a sort of tadpole, and there is little doubt of their relationship. The other group includes a curious sea worm called *Balanoglossus* and a polyp called *Rhabdopleura* which lives in branching colonies that look rather like plants. They are thought to be related because of similarities both in their structure and in their early development; but a few zoologists doubt the relationship. Still more remotely related are the echinoderms such as starfish and sea-urchins. When adult they have a five-fold radial symmetry like primroses or apple blossom. But they grow from bilaterally symmetrical embryos like vertebrates. And the chemical processes which go on when some of them contract their muscles are like those in vertebrates, and unlike those in molluscs and insects.

Quite recently White, of the Natural History Museum, has described a fossil called *Jamoytius* from the Scottish Silurian. This was a soft-bodied animal with few or no bones, about seven inches long. It had no jaws and no paired fins, but a pair of large eyes. At first sight it might perhaps be taken for a worm. However, a glance shows that it was a primitive vertebrate or, rather, chordate, somewhere between the lampreys and the lancelet, which is a headless sand-burrowing, fish-like animal. There were already fishes at the time when *Jamoytius* lived, so it can no more have been one of our ancestors than can any of the monkeys alive to-day. But, like the monkeys, it gives a fair idea of what our ancestors were like. This remarkable fossil was acquired by the Natural History Museum in 1914, and has only now been described. The delay was partly due to the fact that methods of study have been greatly improved in the last generation, but largely because palaeontology is very much neglected in Britain, and its museums grossly understaffed. One can imagine what would have been said about the neglect of pure science in the Soviet Union had such a delay occurred there. But it does not occur, because of the large number of palaeontologists who have been trained since the revolution, and the general interest taken in science.

Another palaeontological discovery which throws new light on vertebrate origins was made by Kozlowski in Poland, and confirmed by Bulman in Britain. Among the commonest fossils in the rocks between the Cambrian and the coal measures are what are called graptolites. They have a great variety of shapes, some like feathers, some with elaborate branches, and were clearly made by numerous little polyps which reproduced by budding but did not separate. They were usually thought to have been something like horny corals, floating, or more rarely attached to the bottom or to plants. But when their skeletons are dissolved out of limestone with acid, and studied under a microscope, they turn out to be very like the living *Rhabdopleura*, and therefore related to the vertebrates.

Now evolution may take place in several different ways. A descendant may add on a new stage to the development of its ancestors. Thus many beetles pass through a stage with a long flexible belly, rather like an adult earwig, but later develop a relatively shorter belly, horny wing cases, and so on. There is little doubt that the ancestors of beetles were something like earwigs.

But evolution may occur in another way, which De Beer calls "clandestine evolution". An animal may develop peculiar larval or embryonic stages, such as the caterpillar stage of moths, or the underwater stages of mosquitos and dragonflies. And then it may slow down its bodily development or speed up its sexual maturity so that it never reaches the former adult stage, and may later develop along quite new lines. This is what man has done. Our heads are much more like the heads of baby or even unborn monkeys, than those of adult monkeys. The seams or sutures in a monkey's skull close soon after birth. Ours do not close till we are twenty or more years old, so our brains can go on growing. A gorilla is born with no thick hair except on the head. We mostly remain at this stage. On the other hand our hands and heels have developed on human lines, beyond those of any ape.

It is quite possible that our very remote ancestors were attached to the sea bottom or floated about in colonies. It is perhaps more likely that at a certain stage our ancestors remained motile while closely related animals attached themselves to the bottom. But if you think it is a ridiculous idea that your ancestors were ever sessile animals, it is worth while remembering that you yourself spent most of the first nine months of your life before your birth attached to the end of a stalk and drawing nourishment through it. It may be a century before enough fossils have been studied to make it sure how the vertebrates originated, as it is sure to-day that mammals arose from reptiles. But enough facts are known to make a guess possible. And some of the wilder guesses of scientists a century ago are to-day acknowledged truths which serve as a basis for practice.

UNEVEN DEVELOPMENT

STUDENTS OF HISTORY ARE SOMETIMES SURPRISED that the first State to achieve socialism was not one of the technically and politically advanced countries such as Britain, Holland, the U.S.A., or France, but the former Russian Empire, which was both technically and politically backward. And critics blame socialism for many of the respects in which the Soviet Union is still behind Britain, for example, the lower average productivity per man-hour, or per acre in agriculture, and the lack of various amenities.

A student of animal evolution finds nothing surprising in this fact. The course of animal evolution has been, on the whole, uneven. When a great step forward is made, it is seldom made by the advanced members of a group, but by rather primitive ones. Of course, organic and political evolution are very different, because the latter is partly conscious, and proceeds in part by imitation. Thus during the nineteenth century most European countries set up parliaments on the English model, although very possibly some other democratic machinery would have been more useful.

But conscious imitation plays no part in evolution. Men do not yet know how to control their evolution, still less do other animals. The fact that, say, the mole has become adapted to burrowing, will not cause the rat to develop similar adaptations. On the contrary, as the mole is well adapted for hunting earthworms underground, another animal would have a poor chance of developing on similar lines, owing to competition by moles. On the other hand the example of Britain induced other countries to set up parliamentary governments, and the example of the Soviet Union will lead other countries to adopt socialism. In spite of this fundamental difference, there are certain analogies between organic and social evolution.

In Devonian times, when the Old Red Sandstone was formed, there were a number of groups of fishes, some of which are now extinct. The group which has since been most successful had just started. Its fins are flat, like birds' wings, supported by a number of rays, whereas the fins corresponding to arms and legs in the older groups have a core of flesh and bone or cartilage. The fish which came out of the water at this time, and which were our ancestors, belonged to one of the older and unspecialised groups. They were not so well streamlined as modern fish, and their fins were more easily convertible into limbs. Probably, too, their swim bladders had not been so specialised for floating as those of many modern fish, and they could use them for lungs, as a few fish still do.

The amphibians which were descended from them were much more like fish than are the modern amphibians, such as frogs and newts; and long before they had specialised, some of them evolved into reptiles. The first reptiles, in the upper coal measures, were very clumsy compared to their descendants, and could not lift their bellies off the ground.

In the next period, the Permian, some of the reptiles had already begun to evolve towards mammals, and during most of the Mesozoic era which lasted at least a hundred million years, the land and sea were dominated by reptiles. Some of the dinosaurs were very large. Some flew like bats. Others stood on their hind legs, or went back to the sea like whales. They were obviously the most highly developed animals of their time. Throughout this huge stretch of time our ancestors were animals usually of about the shape and size of rats, and showed no signs of future distinction, though they may have developed warm blood and given up laying hard-shelled eggs.

In the Cretaceous period, when the chalk was formed, most of the great reptilian stocks died out, nobody knows why, and the mammals, the class to which we belong, became dominant. Once more, most of them specialised. Some developed hoofs and grinding teeth, and became the ancestors of deer, cattle, camels, horses, and so on. Others specialised for gnawing, like the rats and squirrels, or for hunting, like the wolves, lions, and weasels. Others went in for more extreme specialisation, which culminated in highly modified forms such as bats, whales, moles, and anteaters.

Our own ancestors were among the least specialised. They went in for tree climbing, and kept all their fingers and toes, instead of losing some, like the hoofed animals and the carnivores. They kept most of their teeth, and did not specialise them like the horse or dog. They even kept their tails until fairly recently. In consequence when our ancestors began to walk on their hind legs they had a fore limb which could become an organ of skill. A dog or a horse might conceivably learn to speak since they certainly understand our speech to some extent, but could not develop anything like a hand.

In fact, in animals the development to a new evolutionary stage generally starts in a fairly unspecialised and primitive member of an advanced group. The same is perhaps true of States. Rome was a rather backward member of the group of Mediterranean city States and was probably able to absorb or conquer the others because they had developed a rigid class structure too early.

England was on the edge of medieval Europe, and was feudalised later and less completely than France and Germany. So we were able to build capitalism ahead of the other nations. Russia was again on the edge of capitalist Europe, and had not passed over completely from feudalism to capitalism. This made the Socialist Revolution easier than it otherwise would have been, because in any case a revolution was needed to end feudalism. In 1789 the French took over some British, and still more American, ideas on democracy, and began a new and great era in their country's history. If we are not afraid of applying the ideas current in the Soviet Union to our own affairs, we, too, have a splendid future before us.

CREATIVE MUTATION

IN THIS ARTICLE I SHALL TRY TO DESCRIBE A VERY fundamental piece of research which has just been published in Sweden, and which will certainly be imitated in all countries where agriculture is practised scientifically.

In 1927 Muller published his discovery that X-rays enormously increase the frequency of mutation. For this and other discoveries he has been awarded the Nobel prize for medicine. Let us see what this discovery means. Heritable characters are determined by units in the cells. These units are called genes and are copied each time the cell divides. If the two parents contribute different genes, then when the hybrids are mated together, many new contributions are possible. Thus from a white long-haired or Angora rabbit and a black short-haired, we shall certainly get both long and short hair, both black and white, and perhaps other colours, in the second generation if we breed enough, including new combinations such as black Angora.

If this were the whole story, as the early workers on Mendelism thought, one could never get anything but various combinations of the genes which one put in. It is not the whole story. Once in several million times the gene-copying process goes wrong, and a new type of gene comes into being. This event, which is called mutation, generates a new character which can then be combined with others. Thus the short-haired "rex"rabbit and the "Spencer" type of Sweet Pea were due to mutations, and were combined with various colours as desired.

Muller found that in flies he could speed up mutation several hundred times by means of X-rays. Most of the mutants were less healthy and fertile than the normal; while a few were different but no worse, at least under laboratory conditions.

Stadler applied the same technique to maize, but the products have not yet been of practical value. Gustafsson in Sweden has at last got results of practical importance in barley. He subjected seeds to high doses of X-rays, grew them, and then found abnormal types in the progeny of the plants from the X-rayed seeds. Hundreds of thousands of plants were grown, and among them were several thousand mutants. Most of these were either more or less sterile, or else white-leaved plants which did not grow at all, or pale-leaved ones which grew poorly. For every twenty such pale mutants he found about forty sterile plants, one with a change in shape or size, and one with a physiological change, such as earlier or later ripening, or higher or lower yield of seeds. The large majority of these new forms gave worse yields than the parents, a few were as good, a very few were better. Gustafsson thinks that about one mutant in seven hundred is of any real value in agriculture.

However, at least ten superior strains were raised, The most striking one arose in a barley which gives the highest yields of any Swedish type, and which breeders had vainly tried to improve during fifteen years. Now Gustafsson has got a mutant with a ten per cent. higher yield. Other types have stiffer straw or ripen earlier, and it should be possible to combine these characters with higher yield. Whether this will mean cheaper beer and higher agricultural wages in Sweden or only higher rents and profits, is for the Swedish to determine.

The most interesting case for biologists was a yellowish-leaved mutant which gave a yield ten per cent. below the mother type in southern Sweden. But six hundred miles farther north it gave a twenty-five per cent. higher yield. It appears to be adapted to the long days of an Arctic summer, and strikingly bears out the view held by many students of evolution that even apparently unfavourable variations may be of great value to a species by enabling it to extend its range.

In the long run Gustafsson's most important discovery may be that he can control the direction of mutation to some extent. He obtained mutations of rather different types according as he used his X-rays on dry or wet seeds. He is now working on a large scale to find out under what conditions mutants with increased vitality are produced. This may seem a big task. But it is perhaps worth mentioning that Gustafsson is a poet as well as a biologist. Now one of the essential qualifications of a poet is that he must not be afraid of making a fool of himself. If he is afraid, he will probably turn out second-rate imitations of the work of poets of earlier generations. The same qualifications are very necessary if one is to make any great advance in science. So Gustafsson may fail completely. But he may discover something of fundamental importance both for agricultural and for theoretical biology.

Valuable results have also been obtained with flax. It is very much harder to produce much change in wheat, because most of our wheats have three sets of chromosomes in each pollen grain instead of only one, and if a gene is only changed in one set, this has little effect on the plant. However, a beginning has been made. As early as 1935 Sapehin in the Soviet Union had obtained a number of mutants in wheat with X-rays and stated that this method was becoming valuable. Unfortunately no results of field trials have been published as yet. It may well be that the stations where his mutants were being tested were all overrun by the Germans. It may be that results will yet be published. Only in April of 1946 the Moscow Academy of Sciences published a work on a similar question by Graziansky, who was killed in the battle of Leningrad in 1941.

No economic results from such work have been published in Britain. Our lives may depend on the productivity of our crops in the future, but in research of this kind we are a long way behind countries such as the United States, the Soviet Union, and Sweden, where it is less urgently needed. Plants improved by these methods in foreign countries are of little use in Britain. And it takes ten years or so to produce new varieties of agricultural plants, test them, and distribute the seed. So unless such work is started now, our children may be hungry in 1960.

ANIMAL GEOGRAPHY

WE HAVE ALL HAD TO LEARN A GOOD DEAL OF human geography in connection with the war; and we certainly need it if we are to follow the new boundaries being created in the world. For example, we need to know that before the war there was a certain boundary between the States of Italy and Yugoslavia, and another different boundary between districts where most people spoke Italian, and those where most people spoke one of the Yugoslav languages. These boundaries between peoples sometimes run along natural lines such as mountain ranges, branches of the sea like the Straits of Dover, or great rivers like the Danube or Rhine. Sometimes they have no relation to natural obstacles.

We are apt to say that this is a product of human stupidity, and is in some way unnatural. But just the same is true of animals. Every species of wild animal lives in a certain area, and not outside it.

The area may be a very large one; but this is generally because the animal in question follows men, like the mouse or the housefly. However, some genuinely wild animals have a very wide range. For example, the common fox lives in

Europe, Siberia, Canada, and the northern United States, and though the foxes of Britain and Labrador, at the two ends of the range, differ, they probably belong to the same species. Or a species may be confined to a single small island, as some tortoises both in the Pacific and Indian Oceans; or in the case of fish, to a single lake or river. There are probably less than two million species of animal, and some day I hope all their distributions will be mapped. But already we can find some regularities. If we consider land mammals, that is to say warm-blooded animals which suckle their young, there are none in Antarctica apart from seals, and the one rat in New Zealand probably came in a canoe. Those of Australia and New Guinea are quite distinct from those of the rest of the world. A few lay eggs like the duck-billed platypus. The others are marsupials like the kangaroo and wombat, and bear tiny embryos which grow up in a pouch. The baby of a large kangaroo is only as big as a bean. There are a few marsupials in America, but all the higher mammals in Australia, except bats and possibly some rats, were brought by men.

Madagascar and South America have animal populations decidedly different from the rest of the world, though not so different as Australia. Madagascar specialises in lemurs, and South America in sloths, armadillos, and anteaters, and in tail-less rodents like the guinea pig, some of which are quite large grazers, and take the place in nature which is occupied by small deer in other continents.

The rest of the world is less distinctly divided, but Africa, south of the Sahara Desert, forms a fairly separate region, with some overlapping in Egypt. So does India with south-eastern Asia. while the separation between North America and Europe with temperate Asia is less definite.

These facts are geologically explicable. For example, Australia has been more completely separated from Asia in the past than it is now. Many of the islands in the Malay Archipelago have risen out of the sea fairly recently, and new ones are being raised by earthquakes and volcanic action at the present time.

Very few wild animal species are found in more than one of these regions, and many are restricted to a small part of one of them. It is far from clear what prevents their spreading. For example, around London we have three species of newt, all of which are also found in France. But only the smallest one, the palmate newt, gets as far as western Scotland or Cornwall. On the other hand the common newt is found much farther north in Norway and Sweden than the other two species. Nobody knows why this is so.

Boundaries between species are seldom sharp, like human frontiers. For example, the crested newt is found in western Europe as far as the Loire valley in France. In Spain it is replaced by the marbled newt. In central France the two species overlap. But they do not fight one another. On the contrary they interbreed, and as the male hybrids are quite sterile, and the females fairly so, this means that if one species is very rare in a particular area, members of it are likely to mate with the commoner one, and thus to have no grandchildren.

Sometimes two related species give fertile hybrids, and where their areas overlap there is a belt of territory with intermediate forms. Thus the carrion crow, which is solid black, lives in England and western Europe, the hoodie crow with a grey hood, in central Europe, northern Scotland, and Ireland. The frontier zone, with intermediate forms, is about fifty to a hundred miles wide, and runs through central Scotland, and from Kiel to Genoa. The hoodie crowland has an eastern frontier in the Yenisei valley, and beyond this carrion crows are found again. These frontiers are like the frontier between pale and dark-skinned humans running across the Sahara Desert, except that the two crow races do not oppress or fear one another.

Are there language frontiers in animals, too? The answer is uncertain. Wolves do not usually bark, but they can learn to do so within a week if kept with dogs. And the songs of some, but not all, birds have to be learned by each new generation. Since singing plays an important part in the courtship of many birds, differences in learned song might split a species. It is possible that this process has happened. Thus the chiffchaff, willow-warbler, and wood-warbler are so like in appearance that they were first separated by Gilbert White in the eighteenth century by their songs, and only later were physical differences found. Unfortunately we do not know whether they will breed together in captivity. They rarely if ever do so in nature. In such cases as this it is quite possible that an animal species is in the process of splitting up on a basis of the songs which they learn in infancy, as our own species is unfortunately split up on the basis of the languages which they learn.

It is false and dangerous to apply notions derived from animal biology directly to human affairs. That is what Hitler tried to do, though in fact the zoology in *Mein Kampf* is as incorrect as the history. Nevertheless animal behaviour gives us a background against which to study human behaviour. And the study of animal geography is essential both for a proper use of the world's natural resources, and for the study of evolution.

ANIMAL HISTORY

ONE HAS TO LEARN SOME ANIMAL GEOGRAPHY before one can understand animal history, just as with human history. It is not much use learning about the Roman Empire if you don't know whether Rome is in Italy or America.

Human history is mainly the history of human customs, and we know very little of animal history from this point of view. Nevertheless animals do change their customs. A striking example is the change in the habits of our dogs brought about by the muzzling orders of the 1890's. All British dogs were muzzled for some months to check the spread of rabies. Elton has observed that after this date dogfights have been far less bloody than they were before, an interesting argument against those who say "you can't make men good by Act of Parliament". Apparently you can make dogs good.

Again the English robin is notoriously unafraid of men, whereas the robins in many parts of Europe are shy woodland birds which never approach houses. Perhaps this is because we do not eat small birds in Britain. No one knows whether this tameness is inherited or learned.

But most animal history is the record of the slow changes in form which we call evolution, and of migration. One cannot understand evolution without a knowledge of animal migrations. For example, if an archaeologist, ten thousand years hence, tried to reconstruct the history of man in the American continent, he would find a very sudden jump from the primitive cultures of its early inhabitants to the more complex one brought over by Europeans.

He would be wrong to suppose that the complex culture had evolved in America. European palaeontologists made the same sort of mistake about horses. As there were no wild horses in America when Europeans discovered it, it was natural to think that horses had evolved in the Old World. And a good many bones and teeth of primitive horses were found in Europe which made this seem probable. There were gaps in the evolutionary history, but it was hoped to fill them. However, it is now quite clear that horses evolved mainly in North America, where there is a fairly continuous series of skeletons, and that on at least five occasions horselike animals invaded the Old World over what are now the Bering Straits. Surprisingly enough, after the last invasion, horses were wiped out in America, though fossils of horses of quite modern types have been found there. No one knows whether they were killed off by disease or eaten by primitive men.

No group of animals is better known in the fossil state than the elephants. This is not only because their bones are large, but because both their trunks and their cheek teeth are quite unlike those of any other animals. So we know in what areas elephants lived at different times in the past. If we study the history of one particular group of elephants, the mastodons, we find something very like the history of a human empire. They arose in North Africa in the early Oligocene period about thirty million years ago, from animals superficially like the modern tapirs, and not much larger than pigs. In their first six million years they had reached France, Ukraine, and the borders of India. In the next twelve million they had spread over most of the Old World, and finally burst into America. A million years ago they were found everywhere except in the polar regions, Australia, Madagascar, and some other islands. They were very successful animals.

Then came the Ice Ages. Though the ice did not come very far south it caused great climatic changes everywhere, and the mastodons, which had apparently been so successful, could not adapt themselves. At the end of the Ice Ages they were confined to parts of North, Central, and South America, where they survived so late that incompletely decayed corpses have been found in bogs in New York State, and we even know that they were hairy, and ate pine twigs. In South America at least the last mastodons were killed off by men. The skeleton of one was found under a landslip in the Andes, surrounded by the ashes of fires used in cooking its meat, with pottery and stone tools which allow us to date its death at about 200 A.D. Some of the queer figures in Mayan sculptures from Central America probably represent elephants. The last survival of the mastodons in

America reminds one of the Roman Empire, which survived in what are now Greece, Bulgaria, and Turkey for a thousand years after Rome itself had been conquered by German tribes. The living elephant species are not so far from their original homelands.

There are plenty of such survivors of former animal "world-empires". The crocodiles, which live a highly specialised life in tropical rivers and swamps, are all that survive of the great group of Archosauria, or "ruling reptiles", including the dinosaurs, which were once the largest animals in almost all lands. Newts and salamanders represent the amphibians which were the first vertebrates to colonise the land, but were later mostly replaced by their descendants, the reptiles, birds, and mammals.

Another very important branch of animal history is that of the domestic animals. In a sense they have been made by man, for they are very different from their wild ancestors, and the differences are largely due to deliberate human selection. But in another sense they made man. Their influence has been good in some respects. They took over a lot of work, such as transport and ploughing, which was first done by human labour, and thus made civilisation possible. But they were also responsible for some of its worst features. Cattle and capital are derived from the same Latin word, and cattle were the first form of capital. The owner of a flock or herd could and did exploit hired labour. And as the Bible story of how Laban and Jacob swindled one another shows, many of the nastier features of capitalism were early associated with the ownership of cattle.

Animal history is of great interest, but it is utterly unlike human history in two respects. When a State comes to an end, that does not mean that its people perish. On the contrary the conquered often breed quicker than the conquerors, and may furnish most of the ancestry of later generations. Whereas if an animal species perishes it leaves no descendants, though, of course, a species may disappear through evolving into one or more new species. Also animal species rarely fight. One replaces another because it is better adapted to a particular form of life, as, for example, the grey American squirrel has crowded out our brown species from much of England. That is why the Darwinian struggle for existence is, on the whole, a much more progressive agency than human war, and is one of the reasons why the attempt to justify war on Darwinian grounds has no validity.

MEN AND WOMEN

ONE OF THE MANY PREJUDICES WHICH SLOW DOWN the spread of liberty, fraternity, and equality is the prejudice of one sex concerning the other. In our own society the prejudice of men against women is the more harmful as it leads to such injustices as lower rates for women on the same jobs as men. But there certainly is prejudice the other way. Many women seem to think that a man cannot even sew on a button and, what is more serious, that men have no taste, and should not be consulted in planning a home.

The scientific investigation of differences between the human sexes has hardly begun. But we do know enough to refute many of the false statements which are commonly made. There are, of course, absolute differences between the sexes. So far as we know these are entirely concerned with reproduction. With regard to a few other characters, such as hair on the chin and the pitch of the voice, the difference is almost absolute, though I know at least one woman who has borne several children, whose beard would not disgrace a man. But for the vast majority of physical characters there is a good deal of overlap. On an average, men are taller and heavier than women, but plenty of women are taller than most men, and an equal fraction of men are shorter than most women.

I think there can be no doubt that this difference is not due to different upbringing. British women are probably no worse nourished than men, and on an average they live a good deal longer. More men than women died of disease, and far more died of violence in England and Wales in 1938 although there were more women than men in the country. The number of women who died of childbirth and its complications about equalled the excess of male over female suicides. So women are probably not handicapped physically, though they are so mentally, by their surroundings in England. Things are very different in such countries as India, where women on the whole have even shorter lives than men.

The sexes differ in athletic performances in the same way as in height. If we compare the performance of a group of boys and girls of the same age at a hundred yards race, a long jump, or any other such test, the boys will do better than the girls on the average, and the best performance of the boys will usually be better than that of the girls. But once more, plenty of girls will do better than most of the boys. You certainly cannot predict with any confidence that a boy will do better than a girl of the same age. The athletic performance in which the sexes show least difference is long-distance swimming. Here women get an advantage because they generally have more fat than men just below the skin. Hence they lose less heat in cold water. So quite a number of women have swum the English Channel.

When it comes to mental tests, men do better than women at some of them on an average, and women beat men on others. For example, women commonly beat men on tests involving knowledge of words, while men win on tests involving an understanding of mechanics. The scores of intelligence tests are generally adjusted so that on an average there is no difference between the sexes. They can easily be arranged to favour either sex, and any differences in average scores can be explained either by differences of upbringing or by the design of the tests.

But a very curious fact emerges. Boys are much more variable than girls in their performance. In a test on 87,500 Scottish children the average scores of the sexes were practically the same. But the top one per cent., that is to say the best 875 children, consisted of 517 boys and only 358 girls. Just the same happened at the bottom. Idiocy, imbecility, and feeble-mindedness are considerably commoner in boys than in girls. It is impossible to explain this fact, which has been confirmed in America and England, by the theory that more trouble is taken to educate boys than girls. If this were the reason there would be fewer very dull boys than girls. I think the difference is a real one, but it is certainly not enough to justify the unfair treatment of women as regards university scholarships. If the ablest one per cent. of children got such scholarships, about half as many again should be given to boys as to girls. Actually the disproportion is far greater.

Even if very high intellectual attainment is a little rarer in women than in men, there is no doubt that in our society we waste a larger proportion of the talent of women than of men.

COUSIN MARRIAGE

THE WHOLE SUBJECT OF HUMAN REPRODUCTION IS surrounded by superstitions, some of them disgusting and harmful, and it might well be that the objection to cousin marriage was only one of them. However, careful scientific work shows that the children of such marriages are specially liable to some kinds of abnormalities.

The investigation can be done in two ways. Sjögren, a Swedish doctor, investigated all the blind children in Sweden whose blindness was associated in a special way with idiocy. Children afflicted with what is called juvenile amaurotic idiocy are normal up to the age of about seven years. They then lose their sight, later become idiotic, and finally die at an average age of eighteen. The disease is not hereditary in the ordinary sense, for its victims never have children. But it frequently occurs in several brothers or sisters, and also in cousins. Above all, it is relatively frequent in the children of blood relations. Out of Sjögren's 120 cases, no less than twenty-three were the children of first cousins who had married, and another thirty-one were the children of less closely related cousins. Since about one marriage per hundred in Sweden was between first cousins, this means that such a marriage is about thirty-five times as likely to produce an idiot of this kind as a marriage between unrelated parents. Very similar results are obtained for other abnormalities, including comparatively mild ones such as albinism, and serious disabilities such as deaf-mutism.

Dr. Julia Bell, working for the Medical Research Council, tackled the problem from another angle. Over 50,000 adult English hospital patients were asked whether their parents were related, and the same question was put to the parents of over 10,000 children in children's hospitals. The results were very striking. About one adult hospital patient in 170 was the child of two first cousins, but for some rare diseases the number was one in six, and for club foot one in thirty-two. The most serious disease which is appreciably commoner in the children of first cousins is cancer of the womb. I must emphasise that most diseases do not behave in this way, even where there is reason to suspect that an inborn weakness plays some part in causing them. For example, hernia, which is due to weakness of the abdominal wall as well as to strains on it, does not pick out the children of related parents. Mental defect is also commoner in the children of related than of unrelated parents, though inbreeding is not one of its main causes.

Inbreeding has similar effects in animals. If we mate brothers and sisters of a species which is normally outbred, we invariably find abnormalities, ranging from slight colour differences from the normal type to legs growing where an insect's feelers should grow. The reason is quite clear.

The characters which appear as the result of inbreeding are what are called recessives. Such characters only appear if a child gets an abnormal gene from both parents. I probably carry an abnormal gene for some character of this kind, perhaps albinism, juvenile diabetes, or some disease of the nervous system. If I married my sister there would be one chance in two that she would carry the same gene, which would produce abnormality in about a quarter of our children. If I married a first cousin the chance would fall to one-eighth, and to smaller values for remoter relatives.

Curiously enough the Eugenics Society has never undertaken a campaign to discourage cousin marriages. The Catholic Church nominally does so, but it is so easy to obtain dispensation to marry a first cousin that such marriages were actually commoner in Catholic Bavaria than in Protestant Prussia; and in fact the prohibition is a source of income to the Church rather than a check on such marriages. The Greek Orthodox Church, on the other hand, forbids such marriages absolutely. If they were forbidden in England, we should have something like 6,000 fewer mental defectives. 2,500 fewer deaf-mutes, a few thousand less cases of some rare diseases, and perhaps a few hundred less deaths per year from cancer of the womb. Nevertheless I am personally against any such prohibition, first perhaps because I am rather strongly attached to liberty, and secondly, because the rate of cousin marriage is falling rapidly, since modern conditions give people a much wider choice than they had a generation ago. In fact, rural motor buses may be quite an important eugenic agency.

I think, however, that everyone should understand that, if they marry a first cousin, they are more likely to have an abnormal child than if they marry someone else. The probability is not very great. For example, something like one child in 120 becoming a mental defective. The frequency is perhaps one in forty among the children of first cousins. If this were generally understood, people who were deeply in love would take the risk, as they take a risk when they marry someone with a bad temper or a nagging mother; but a good many would not. Though I am against making cousin marriage illegal, I do not think such a prohibition would be unjust. It could not be used as a weapon of oppression, as sterilisation was used in Germany. It would not make people who are already unfortunate still unhappier.

The fact that eugenic legislation has nowhere been directed against inbreeding, which is a serious source of congenital disease, is certainly an argument for the opponents of eugenics, who think that the eugenic movement is motivated by class hatred or a desire to mutilate our fellows, rather than a genuine wish for racial improvement.

RACE, RELIGION, AND CRIME

THE NAZI RACIAL THEORY STATES THAT OTHER races are inferior to the Germanic, and in particular that the Jews are men and women of criminal propensities, out to wreck civilisation. Though they abuse the Jewish religion, the Nazis think that people of Jewish origin whose ancestors have been Christians for several generations, are as evil as Jews who keep every item of the Mosaic Law. They are only a little less critical of other races. The Negroes are only fit to be slaves. The Russians are Asiatic. The well-known perfidy of the English is due to the intermarriage of the Angles and Saxons with the Welsh, thus contaminating their Nordic blood. A fair number of people in Britain and the U.S.A. hold similar views which are used to justify imperialism and the unfair treatment of coloured people.

The Dutch criminologist Bonger, who was professor of sociology and criminology at Amsterdam, completed a book in 1940, which was translated into English, and published* in 1943 under the title *Race and Crime*. The author committed suicide when the Germans occupied Amsterdam. The book is rather stodgy, but its statistical tables tell very clear stories. Unfortunately there are no data from Britain. We know what proportion of criminals say that they belong to various religions, but we do not know the proportions in the whole population. So, except in a few cases, of which one is considered later, no comparison can be made.

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*Columbia University Press, New York.

The data about Jews in Germany, Austria, Poland, and Hungary, are quite clear. Jews were less likely than others to commit murder, manslaughter, assault, theft, receiving stolen goods, embezzlement, or sexual crimes such as rape. They were more prone to fraud, forgery, swindling, and fraudulent bankruptcy. In Germany they were a little more often guilty of insulting behaviour. But on the whole they committed less crimes than the rest of the population. The differences are enormous in some cases. Theft and murder in Germany were about three times as common among non-Jews as Jews. But fraudulent bankruptcy in Hungary was forty times as common among Jews as among others, and twelve times as common in Austria. If fraudulent bankruptcy is worse than murder, this is, of course, a reason for anti-Semitism.

In the Netherlands there are figures not only for Jews, but for Protestants, Catholics, and members of no church. In round numbers, fifty-four per cent. of the Dutch were Protestants, thirty-five per cent. Catholics, two per cent. Jews, and seven per cent. irreligious. The numbers convicted annually per 100,000 members of each religious group between 1901 and 1909 were 416 Catholics, 309 Protestants, 213 Jews, and 84 of no religion. This is, of course, a complete refutation of the view, which we can hear on the B.B.C., on most Sundays, that religion is needed for morality. It is probably due to the fact that most of the members of no church were socialists who took their obligations to the community seriously. This is borne out by the fact that the one crime which was as frequent among them as among others was "rebellion against authority". The Jews, though law-abiding on the whole, had bad records for receiving stolen goods, embezzlement, and swindling, and ranked between Catholics and Protestants as regards murder. The Catholics were slightly worse than Protestants in almost all respects, but there was no outstanding feature.

In 1931 to 1933 the differences between the religious groups were far less, and the Jews were intermediate between Catholics, who still had the worst record, and Protestants. The most striking change was that the Jews now headed the list for rebellion against authority, though they were below even the churchless as regards the frequency of murders. It looks as if they had become more conscious of social injustices, and were not very tactful in their protests.

I have little doubt that English statistics would tell a fairly similar story. We should find the Jews less likely to commit crimes of violence, and more likely to commit various kinds of fraud. This is natural enough. An agricultural labourer or a miner has very poor opportunities of committing forgery or fraudulent bankruptcy. A shopkeeper has many opportunities. A Jew is more often a shopkeeper than an agricultural labourer or a miner. Unless we know what fraction of shopkeepers were Jews, how many shopkeepers were guilty of fraudulent bankruptcy, and how many of these were Jews, we cannot say whether a Jewish shopkeeper is more likely to commit this crime than his Christian or atheist neighbour.

Certainly economic position is quite as important as race or religion in determining crime. Thus in Germany from 1874 to 1896 arson was eighteen times as frequent among agricultural workers as among the professional class, while rape and such like crimes were equally common in the two groups. Ricks and barns are very easy to burn if one loses one's temper.

National tradition is equally important. About 1930 one in every 4,500 Bulgarians was convicted of homicide each year, which is about 100 times the rate for Norway, or for England and Wales, the least murderous European countries. Lithuania, Latvia, and Estonia were also very murderous, while Greece, Poland, Portugal, Finland, Hungary, Roumania, and Italy were pretty bad. Is this a matter of race? In Massachusetts from 1914 to 1922 persons born in Italy were eight times as likely to be convicted of murder, manslaughter, and assault, as persons born in America. This looks bad for the "Mediterranean race" till we discover that persons born in America, but one or both of whose parents were born in Italy, had just the same conviction rate as American-born children of American parents.

American Negroes certainly have a higher frequency of most crimes than whites of the same sex, but white men are much more criminal than Negro women, let alone white women. So if Negroes should be stigmatised as a criminal race, males should be branded as the criminal sex.

No one knows whether, if they were brought up in precisely the same environment, people of Jewish origin would be more or less prone to any particular sort of crime than others. We do know something about the effect of special teaching. Sir Percival Sharp found that in Liverpool 4.55 per cent. of the children in Catholic schools were brought before the Juvenile Courts, 3.56 per cent. of those in Anglican schools, and 2.16 per cent. of those in Council schools. Similar results were obtained elsewhere. Of course, it can be argued that the church schools were mainly in slum areas. If so, one can only say that good housing makes better children than religious teaching. Probably any teaching, whether in sectarian schools or "public" schools, which makes a set of children think they are better than their neighbours, tends to make them bad citizens.

Some day we may know whether racial differences are of any importance at all in determining crime. But we know already that they are far less important than differences in education and tradition.

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CAN WE CHANGE HUMAN NATURE?

AFTER A LECTURE WHICH I RECENTLY GAVE ON the question—"Are we losing our morality?" someone asked me, "Can you change human nature?" I don't know the answer, because I don't know what "human nature" means. But if you put the question in the more concrete form—"Can one change the sort of things which people want to do?"—the answer is undoubtedly yes. In one type of society competition is a strong motive, though it may be competition for money, the esteem of one's fellows, or the prospect of escaping hell-fire. In others co-operation is an equally strong motive. People want to work with and for others, and are not interested in excelling them. Probably the ideal is a blend of the two, where everyone tries to be useful, but is quite pleased if he is more useful than his neighbour.

When a scientist is asked a question of this kind, he often gets a great deal of information from animals. One can experiment on them, and they are less likely to do what is expected of them to please Mummy or teacher; and therefore one gets a clearer answer.

The cat is a good subject for experiments of this kind, since it is harder to train than a dog, and less susceptible to reward or punishment. In the experiments which I am going to describe, Zing Yang Kuo, of Hangchow University, tried to get an answer to the question: "Is it part of the nature of cats to kill mice and rats?" He worked on fifty-nine kittens, divided into three groups. Each member of Group A lived with a rat or mouse from the age of a week upwards, except that until it was weaned at about a fortnight it was put with its mother at night. Group B was kept in solitary confinement in cages after weaning, except for the tests described later. Neither Group A nor Group B was allowed to see the mother kill a mouse or rat. Group C lived with their mothers throughout the experiment. And every four days they saw their mother kill an animal which might be a white rat, an ordinary mouse, or a small dancing mouse. The mother was not allowed to eat it, and each mother cat killed only one kind of animal.

From the age of a week onwards, the following experiment was done on each kitten every fourth day. It was put in a cage with a white rat for half an hour, then with a large mouse, and finally with a small dancing mouse. The experiments went on till the kitten either killed one or more animals, or reached the age of four months.

The results were absolutely conclusive. Only three of the eighteen kittens of Group A ever killed an animal. In no case did they kill an animal of the kind with which they had been brought up. On the contrary they treated such animals with friendship. Nine out of twenty kittens in Group B killed an animal. They were more likely to kill a mouse than a rat, and a small mouse than a large one. If they had killed a large one, they usually killed the smaller ones also. But less than half of them ever killed one.

Finally eighteen out of the twenty-one kittens in Group C were killers. In almost every case the animals first killed was one of the kind which they had seen their mothers kill.

Diet had no effect. Half the kittens in each group were given meat, the others were not. The meat-eaters were no more likely to kill, but if they did so they were likely to eat their victim. Nor did it make any difference whether a kitten had just been fed, or had gone without food for twelve hours before the test. In the absence of previous experience, hunger does not make a kitten violent.

The experiment went on. The pacifist kittens of Groups A and B were given another two months during which they could see other cats killing mice or rats. Nine out of the eleven kittens of Group B fell for this propaganda, but only one of the fifteen kittens in Group A, which had lived with a mouse or rat.

I have no doubt that there were innate differences between these kittens as well. If Mr. Kuo had bred from the three pacifist kittens of Group C and gone on selecting those which did not kill even when they saw their mothers doing so, he could probably have produced a race of cats which never killed mice or rats. Similarly he could have bred a very fierce breed from the killer kittens of Group A. Whether such a result would need ten generations or several thousand I do not know.

But ten generations are quite enough to separate out groups of rats with very different abilities as regards finding their way through mazes.

Nevertheless it is quite clear that the education of these kittens counted for a great deal more than any inborn differences which may have existed between them. The evidence of anthropology is very strong that the same is true for men. And, of course, with human beings precept as well as example counts. Though I don't think it counts for as much as some people think. The example of parents who behave decently is worth any amount of "pi-jaw" from parents who do not. However, that is only my personal opinion, and is not based on any statistics.

My attention was called to Kuo's work by John Cohen's *Human Nature, War, and Society*, a book with which I disagree because, after an excellent start, it never deals seriously with the fundamental question: "What types of social structure lead to war?" Mr. Cohen may well believe that the Marxist answer to this question is incorrect, but he is not likely to win Marxists over to his views if he ignores it. Nevertheless the history of Kuo's kittens is only one of his arguments to show that war is not an unavoidable evil rooted in human nature. The next step in the argument, if we want to do something practical, is to show that the basic causes of wars, even of those fought in the name of superior religions or superior races, are mainly economic, and then to do our utmost to abolish the economic causes of war.

HEREDITY AND ENVIRONMENT

DURING A RECENT LECTURE TOUR IN SWEDEN AND Denmark, my wife and I spoke on our recent scientific work, and we met a number of scientific colleagues engaged on similar research. Most of the research on animal and plant breeding in Sweden has very definite practical ends in view, but it is carried out so as to yield results of general scientific interest. In particular some of it illustrates very beautifully the way in which heredity and environment interact.

At Wiad, near Stockholm, Professor Bonnier has a great barn full of cows; for, of course, cows must be kept indoors during the Swedish winter. Among them are over fifty pairs of twins. Most cattle twins are no more alike than other whole brothers and sisters. But about one pair in twenty-four are monozygotic, or "identical", twins derived from the same egg. A pair of such twins looks extraordinarily alike, but if they are piebald, like most of those which I saw, they can always be told apart. If one has a white patch on the shoulder so has the other, but the shapes differ slightly. Twins of this kind are much commoner among men than cows. About one human twin pair in four is monozygotic. Such a pair has received just the same hereditary materials from their parents and if brought up together resemble one another very closely. This has been said to prove the omnipotence of heredity.

If such a pair of twin cattle is kept on the same meadow or given the same ration, their growth curves and milk production are almost indistinguishable. It follows that if they are fed differently, the difference will mainly be due to environment. If you take a pair of calves born on the same day in the same herd, one will grow quicker than the other on the same ration. If you give one more food than the other, the better fed one will generally grow quicker, but not always. To make sure which is the better of two diets, you must test a number of pairs. But with a pair of monozygotic twins there is no doubt. In fact Professor Bonnier finds that to distinguish between two environments by experiments on twins he needs one-twentieth of the number of cattle that he would need if he used the older methods. So almost all the twins were being used in this way. One of each pair had a restricted ration. They certainly did not look starved, and probably got more food than many cattle on poor farms; but they were distinctly smaller than their sisters.

One of the special objects of the research was to determine the effect on milk yield of the diet given to the calves. One calf was fed better than the other till they were mated, and both were then put on full rations either during pregnancy or at least while giving milk. However, this did not suffice to equalise the milk yields. It does not, of course, follow that it pays to give a cow the best possible diet. Indeed the object of the work is to discover what level of feeding will pay the farmer best. Such research will be very important in Britain, particularly with regard to the value of artificial foods, such as oil cakes. I hope that our Agricultural Research Council has its eye on Professor Bonnier.

Dr. Rasmusson, who directs the research of the Swedish Sugar Beet Company, is tackling the problem of heredity and environment from another angle. Beets are continually being selected for high sugar yield, and, of course, for resistance to disease, and unfavourable conditions. Each race is tried in a variety of soils and climates. Most of the beets are grown in a region specially well adapted for this crop. But most of the testing stations are outside this area. For much more work is needed to get high sugar production on poor soils than on good ones. And when this has been achieved, the new race may give a slightly higher yield when taken back to the good soils. More usually this is not so; but it may have some valuable quality which can be combined with those of the races grown on good soil by crossing and further selection. The principle which underlies all this work is as follows. When one is dealing with economically important differences, it can seldom be said that any character is inherited. What is inherited is the capacity for reacting in a particular way to a particular environment.

A certain kind of beet will do best on a particular soil in one year; in a year with different rainfall and temperature it will not do so well.

I have no doubt that just the same is true of men and women. If this were realised I should not get letters asking more or less meaningless questions such as "Is intelligence inherited?" I do not know what determines differences in human intelligence. No doubt heredity and environment interact. I am only sure of one thing, that their interaction will prove to be even more complicated than in the determination of sugar yield in beets.

PART III

SCIENCE AND SOCIETY

WHY PEOPLE FEAR SCIENCE

DURING THE ELECTION CAMPAIGN I WAS SPEAKING at Desborough for the Labour candidate. My chairman made the usual flattering remarks about me, but added that a good many people distrusted scientists. And because I was speaking about science and socialism, for the first time I saw quite clearly why this was so.

Why do so many people hate and fear science? Hitler's V-1 and V-2 weapons were great achievements of applied science. Many Londoners would like to hang the scientists who invented them. And many Germans doubtless feel the same way about the British scientists responsible for our giant bombs. Even in peacetime we must remember that traffic accidents kill about as many people per year as the V-weapons did. You cannot expect a mother whose child has been killed by a speeding car to be a very enthusiastic admirer of the internal combustion engine. Nor can you expect a miner who is coughing his lungs up because he has inhaled dust caused by coal-cutters to be a strong advocate of underground electrification. Finally, you cannot be surprised if a religious man or woman who sees science undermining the basis of his neighbour's religion, and giving them nothing in its place, regards science as a menace to humanity.

As regards the application of science, our answer is quite simple. During a war science is socialised. Most scientists are working primarily to harm the enemy, even though some of their work, including much of my own, will help to save lives in peacetime. But in capitalist countries in peacetime the majority of scientists are working to increase the profits of some firm, a good many to satisfy their curiosity; and only a few directly to make their neighbours healthier, safer, or happier.

It is, of course, essential that scientists should get plenty of opportunity to tackle problems simply because they are interesting, but many of the most interesting questions arise directly from practice. In fact, when a branch of science has been divorced from practice for a generation or so, it may become as intellectually barren as the study of chess problems or postage stamps. Under socialism science is constantly being used to make life longer and pleasanter for the ordinary person, and a Soviet citizen who distrusted it would quite rightly be regarded as a halfwit. In the course of this work enough abstract problems come up to keep the "pure" scientists interested. For example, in order to get efficient underground gasification of coal which, when we have it in England, will convert our Black Country into green and pleasant land once more, one must study a vast variety of problems such as the separation of gases by liquefaction, the heat conductivity of rocks, the problem of sending gas along pipelines for hundreds of miles, and so on.

What about the accusation that science destroys religion and leaves nothing in its place? Communists think that religion is good in so far as it helps a man to realise his proper place in the world and in society, and bad in so far as it does the opposite. Christians who take the Gospels seriously realise that religion begins with love of our fellows. "For he that loveth not his brother, whom he hath seen, how can he love God whom he hath not seen."

Now the essence of science is objectivity. It sets out to give an account of the world which is true for everyone, not just for one man or group of men. In so far as a scientist lives up to this ideal he treats himself objectively. For example, when I am doing experiments on myself I always take my notes in the third person. And this is, of course, the usual practice in my profession. Instead of writing, "I am panting heavily and sweating slightly, but have no headache," I write, "J. H., panting heavily (sixteen respirations in 30 secs.) and sweating slightly. Reports no headache." In fact I try to think about myself exactly as I would about anyone else. Naturally I don't manage to keep up this attitude all the time, not being perfect in any way. But surely such a standpoint is the correct one on which to approach moral, political, and religious questions as well as scientific ones. There is no room in the scientific attitude for such words as "I" and "mine". In so far as a man can adopt it he inevitably finds himself loving his neighbour as himself—and occasionally hating himself as his neighbour. But a scientist does not get his attitude until he studies a branch of science in which he is part of the experiment or observation. That is one reason why human biology is such an important part of any general education. I should like to see elementary schoolchildren taught to make such simple observations as weighing and measuring themselves every month, if only to help them to think of themselves objectively.

No one knows how much of religion will survive when people have ceased to believe in the obsolete science which is associated with all the religions and—what is much more important—when the brotherhood of man has been achieved as a fact rather than an ideal of human behaviour. We can all make our own guesses. My own guess is that we shall turn out to have been asking the wrong questions, as primitive men asked the wrong questions about the sun, for example, whether it went into a hole under the earth at night, or went round from west to east in a boat. And so we have got the wrong answers. And I think the answer that the universe is a machine and men are machines is as wrong as any of the religious answers. Until we can get the right answer, science can give us an attitude to the world which makes the brotherhood of man an obvious ideal, and it can show us the practical means by which that ideal can be made a reality.

SHOULD SCIENCE BE PLANNED?

IT IS OBVIOUS THAT IN WAR SCIENTIFIC RESEARCH must be planned. The majority of younger scientists believe that science should also be planned in peacetime. That is the view expressed by the Association of Scientific Workers. The Royal Society does not commit itself. But it spends about £26,000 per year on research and publication, and, of course, it has to plan how to spend it.

However, a small but not negligible group of scientists is violently opposed to the planning of research. They say that this would stifle originality. If Newton had been under a planning authority, he would have had to devote himself to improving telescopes, and would never have discovered universal gravitation. Darwin would have been put to improving British livestock or listing the economically valuable plants of Australia. He would never have had time to produce his theory of evolution.

The majority of British scientists, they say, work in industrial laboratories where work is planned, but their work is mainly concerned with detailed improvements. The big discoveries which have revolutionised industry were made by men like

Faraday working without any guidance from a planning authority.

Unfortunately some of them spoil their case by saying that Soviet scientists are robots. If so, Stalin or whoever directs them, must be Galileo, Newton, Pasteur, and Darwin rolled into one. He tells one man that he will find a new family of rodents in the Tajik desert, a woman which enzyme in muscle is responsible for contraction, and another man how to solve a problem about prime numbers which has been worrying mathematicians for 150 years! Of course, these discoveries, and thousands like them, were made by individual initiative, for which Soviet planning gives ample scope. This combination is secured in two distinct ways. The first is the democratisation of research. Directors of scientific institutions not only have to listen to directions from superior authorities, such as the Academy of Sciences or the Commissariat for Heavy Metallurgy. They have to listen to the criticism and suggestions of subordinate workers, from lecturers to charwomen. In Britain professors get very little criticism from above, and very often none at all from below. "Freedom of research" is a grand slogan for a laboratory chief who is a little Hitler and objects to planning. It does not sound so grand to the research worker who does not know what the man at the next bench is doing, and is forbidden to ask.

There are two S's in U.S.S.R. One stands for Socialist and implies planning from above; the other for Soviet, means initiative and criticism from below. This two-way traffic of ideas is as vital to science as it is to industry. Without planning, Soviet science would not have shown the greatest growth in a generation which has ever been recorded, and, to take only one example, the Red Air Force would have been many years behind the Luftwaffe in design. Without democracy the Soviet scientists would have made few original discoveries, and would not have had the initiative needed to tackle war problems.

The second feature of democratically planned science is the part-time principle. So far as possible no laboratory is wholly engaged in "pure" research, i.e. research of no immediate value. The workers are asked to spend some time also on research immediately applicable to industry, agriculture, medicine, or war. On the other hand, industrial and military laboratories are permitted some pure research, for example, the Soviet Academy of Military Medicine published work on the chemical changes in developing hens' eggs. These may throw light on wound healing, but have no obvious bearing on war. But unless such work is done, military medicine may lose touch with science. Some capitalist firms allow their scientists great freedom. Thus R. R. Williams works for the American Bell Telephone Laboratories. His main job is to keep telephone poles from rotting and insect attack. I imagine he does this pretty efficiently, for the Bell Laboratories allow him so much time and equipment for his own work that he has isolated a vitamin and worked out its composition. Few British industrial chemists are so lucky.

I believe that British science should and must be planned. But without democracy in the laboratory planning will merely stifle originality. And under capitalism many branches of science, and particularly physics, chemistry, and geology, cannot be adequately planned. Competing firms keep research secret, and monopolists are often more interested in profits than progress. Planning under capitalism has been fairly successful in the fields of medicine and agriculture, as exemplified by the British Medical Research Council and the American Agricultural Research Board. But progressive scientists however much in favour of planning in principle, will do well to beware of plans drawn up to assist industrial magnates, and mine owners. That kind of planning may well be a step towards fascism and the degradation of science.

PLANNING AND FREEDOM IN SCIENCE

THE ASSOCIATION OF SCIENTIFIC WORKERS HAS RECENTLY published an impressive volume on "planning in Science", which records a conference held recently. This is mainly concerned with war problems, but many of the speakers were emphatically in favour of planning scientific research after the war, and this was so regardless of their political views. A minority of scientific workers are opposed to planning. They believe that no great scientific discoveries will be made if research is planned. And some of them have started a "Society for Freedom in Science", which is to spread their views. Dr. J. R. Baker, an Oxford zoologist, has recently published a book called *The Scientific Life*, which states the case against planning, and for what he regards as freedom. Here is part of the programme of the society of which he is a member. "The conditions of appointment of research workers in universities should give them freedom to choose their own problems in their own subject, and to work separately or in collaboration as they may prefer."

Let us examine this demand. First of all it only applies to university research workers, who are a small minority of all scientific workers. It would not apply to workers in hospitals or chemical factories, yet it is in these that most great medical discoveries have been made in the last generation. Nor would it apply to Dr. Baker's laboratory assistant, who might prefer to stuff birds rather than prepare microscopic sections. In fact, Dr. Baker is asking for freedom for people like himself rather than general freedom. Actually this freedom of choice is only possible in some research departments. Where there is complicated and expensive apparatus, this must be used. If a man joins the staff of an observatory whose main telescope is adapted for photography, he cannot switch over to observing the surface of Mars or counting shooting stars. He must co-operate in the work of the observatory. In the same way if animals or plants have been bred for many years, it would be ridiculous to throw away a stock because a new research worker would rather breed butterflies than poultry, or goats than guinea pigs.

Finally notice the words "in their own subject". Oxford has financial provision for zoological research, largely because certain rich people have stumped up the money. It has no provision for psychical research, which is very important if even a tenth of the spiritualists' claims are true, or for research into the life of Marx. Dr. Baker demands the right to study sea anemones even if the State wants him to work on wool production. Why does he not ask to be allowed to study meteorology or archaeology if he wants to?

One of his main arguments is that great discoveries come by chance. For example, Pasteur, working on crystallography, became interested in bacteria which led him to the study of disease, Röntgen noticed that rays from a vacuum tube went through black paper, and so on. Dr. Baker thinks this would have been impossible in planned science. Let us take an example of planned science, Soviet geology. An expedition is sent to look for copper ore, whose presence in a district is suspected. They find very little copper, but a good deal of tin. Does Dr. Baker think that they would not report the tin, or be shot for not finding enough copper?

The planning of scientific research involves a thorough survey of some part of nature, whether it be the rocks of a mountain range, the animals of an island, the properties of a group of chemical substances or of a set of rays. No one knows what will be found, or whether the findings will be put to any useful purpose, but we do know that this is often enough so to make planned research a very good investment for the State. This sort of planning is only harmful if it is so rigid that a researcher cannot follow up an unexpected discovery. A plan for research should be like the plan of a military campaign. This should be flexible, so that it can be altered as the situation develops. A unit which finds a gap must be encouraged to go forward, but not to get lost. Where advance is difficult it may be best to attack harder or to turn the flank.

Planning is obviously necessary in industrial research. Dr. Baker dismisses this by saying that technology is not science. He quotes a Chicago university dissertation on "A time and motion comparison of four methods of dish-washing", which presumably he does not regard as science. But a dissertation on the methods used by mammals for cleaning their fur, which include teeth divided up like combs, special forms of claws, and so forth, would certainly rank as scientific at Oxford. Perhaps Oxford is a little snobbish even in its science. And such snobbery does not make it easy to switch over to war research. Planned technological research can be first-rate science. The theory of sound made no serious progress for a generation until the design of gramophones and loud-speakers broke new ground. Bacteriology did not originate from medicine, but from the study of brewing and other fermentations. Even in peace, and much more in war, most scientists are engaged in technological work. Britain will only hold its place in the world if we make our technology more scientific, and bring our academic research into touch with practical problems. This can be done by a combination of planning with democracy in the laboratory, and in both respects we have much to learn from the Soviet Union.

CAN SCIENCE BE TAUGHT?

ONE OF MY JOBS IN PEACETIME IS TO LECTURE AND hold practical classes on certain branches of biology. This is not essentially different from the task of a secondary school teacher. In each case our pupils are working for examinations, even though many of them are sufficiently interested to study some matters on which they will not be examined. Are we really doing the best we could to turn out the scientists of the next generation? By scientists I mean men and women who actually advance science, either by discovering new facts about nature or by applying those which were known before to practical problems. Of course, the distinction is not a sharp one.

I am inclined to say "No", if only because I have had a fairly successful scientific career without passing any examinations in science since I left school. I had a vastly better training than any university course, namely apprenticeship. The teaching of science involves a contradiction. The very core of the scientific attitude is a respect for facts, whether or not they agree with the teaching of the Bible, of Darwin, or of Engels. But in school one is taught on the authority of the teacher or the textbook. A real teacher of science must persuade his pupils that his lectures may be incorrect, and are bound to be so at some points; whereas the spelling of English or French can and should be taught authoritatively. I learned my most important lessons in science from my father. When I was about eight, I began taking down figures which he dictated to me during analysis. By the time I was twelve I was taking samples of air in mines, and mixing soda and lime for rescue apparatus. Later I came on to the really responsible job of bottle-washing. I realised that the standards of accuracy required in real research, where a mistake might lose a life, were vastly higher than those of school chemistry, just as my own laboratory standard of cleanliness was above that of the scullery. I heard my father producing beautiful theories which he had to scrap in deference to ugly facts. I got at least a rough idea of what scientific research meant.

The most important part of the science teaching which I have done was probably the supervision of young workers doing their first research. They must be allowed to make mistakes—even bad ones which will waste a month—but yet helped, if necessary, so that they get some results from their work. Some of my junior colleagues have done pretty well, and at least two are probably better biologists than myself.

If we are to teach children science, as we do teach them English, up to the point where some of them show at least a little originality, we must introduce something of this kind into schools. This has already been done in many Soviet schools, though presumably their scientific teaching has suffered from the war. In some country schools a party of boys and girls would accompany a geologist on a week's prospecting tour, finding samples of minerals and fossils. In others they helped in the collection of animals and plants. Many schools co-operated in a study of bird migration. Thousands of birds were caught in traps specially designed not to hurt them, released with rings on their legs, and caught again at other schools. When all the results were collated, it was possible to map the routes taken across the Union by various species of birds. In many of the towns workshops were available where children could test their own inventions. Probably very few of these were much use, but at least they learned from their failures. And they had the satisfaction of making something from their own design, instead of merely repeating standard exercises.

How far could our secondary-school children learn science in this way now the war is over? The first requisite is a much bigger and better supply of science teachers, particularly men and women who have done a little research, if only up to the M.Sc., standard. One of the main tasks of our universities should be to produce such teachers. The second is more leisure for the teachers, and for the brightest ten per cent. of boys and girls learning science. This would be available if free university education were provided on the scale of the Soviet Union, or even the United States. If so the ablest children would have qualified for it by the age of fifteen, and would have some time to spare in their last school years.

Under socialism such things would be vastly easier. The State-owned factories and railways could and would be linked up with the schools in a way which is impossible at present. School-children would be more welcome on an estate belonging to their own parents than in Lord Blank's pheasant preserves or Sir John Dash's Home Farm.

Many teachers may think that, at best, such work will not make a real contribution to knowledge. If they think so it is because they themselves have been taught science badly, and do not realise how little we know about quite simple matters. Professor Salisbury, who has just been appointed director of Kew Gardens, has recently published the first comprehensive counts of the numbers of seeds produced by common English plant species. Such figures are most important for the theory of evolution, but had never been compiled before. On an average only one seed per year from an annual plant can germinate and grow up into a new plant. But this one is one in 70,000 with the field poppy, and about one in thirty with the cuckoo-pint. Clearly natural selection is much more intense in the poppy than the cuckoo-pint, even though the latter lives several years. Children could easily undertake such work as this.

Under the new educational schemes children are to be segregated into grammar, modern, and technical schools at the age of eleven. Presumably in the modern schools they will be taught science by the existing methods, while in the technical schools they will have a chance of learning the craftsmanship which every scientist needs, but few scientific principles. In fact, the gap between theory and practice, which is characteristic of capitalism or any other class society, will be made a feature of our education. This may help to delay the coming of a classless society. But it will not give us the scientists whom we shall need if we are to hold our place among the nations.

TEACHING TEACHERS

THE SCHOOL-LEAVING AGE HAS BEEN RAISED TO fifteen, and will eventually be raised to sixteen. An amendment to raise it to sixteen in 1948 was only just defeated in the Commons, partly on the ground that there will not be enough teachers. I am particularly interested in this question because I am a university professor, and one of my main jobs ought to be the training of future teachers. I should like to see every secondary-school teacher educated up to the university honours standard. For you cannot teach a subject really well unless you know a good deal more about it than you normally have to teach. You are then in a position to answer your pupils' questions, and above all, to show them in a rough way how the subject taught links up with other branches of knowledge, and with the life of society.

If the training of teachers is to be one of the chief functions of a university, the universities should adapt their courses to this new need. I am engaged in the teaching of biology. At present a student in London University who is interested in living things has two alternatives. He or she may take a general degree in three scientific subjects, such as zoology, botany, and chemistry, or a special degree in one subject such as zoology, with a slighter knowledge of other subjects. The class of honours depends on the special subject only.

Besides teachers, agricultural scientists ought to know a good deal about both plants and animals. Thus a man or woman who is to work on root crops must know not only how to cultivate and breed them, but about the insects and other animals which attack them. A specialist in dairy farming should not merely understand cows, but also meadow grasses and the methods of improving their quality. Both should know some bacteriology to enable them to deal with diseases of root crops, and to test samples of milk.

So a number of teachers in London University are discussing the possibility of an honours course in biology as a whole. This would be a much better course to-day than it could have been in 1900, owing to the growth of knowledge in subjects which cut across the frontiers between plant and animal life.

One of these is biochemistry. We need a good milk supply to provide us with first-class proteins, especially for growing children. But the cow is only able to make the milk proteins from proteins present in the grass she eats, and the grass can only make them if enough nitrogenous compounds are available in the soil. Again, although the forms of the cow and the grass are very different, the chemical compounds and the processes going on inside them are more similar than was realised until recently. For example, the grass roots need energy to grow, and to suck in nutritive substances;

and they get it by oxidising food just as the cow gets the energy needed for walking and eating. The chemical machineries of the two processes are so alike that one can learn about one by studying the other.

The principles of inheritance in animals and plants are extraordinarily alike. Some can be most easily studied in plants, others in animals. A good course in genetics should jump from plants to animals, and back again. For example, inbreeding has good and bad effects. These are most easily studied with the most extreme form of inbreeding, namely self-fertilisation, which is possible in most plants, but in very few animals. On the other hand if large numbers of individuals are needed, it is vastly easier (particularly in London) to grow a thousand small insects in ten milk bottles than to grow a thousand wheat or pea plants. And the fact that in most animals the sexes are separate, while in most plants they are combined in the same individual, introduces an extra complication into animal genetics.

Ecology, the study of living communities, is a study of both plants and animals. The ecologist investigates an area, whether natural like a moor or a lake, or artificial like a meadow or a reservoir, and begins by making a list of the plant and animal species, with a rough estimate of their frequency at different times of the year. He then determines which eat which, and how they compete with one another. For example, it is not only rabbits above ground, but wireworms below it, which may compete with the cows in the meadow for grass. Bacteria in the soil may destroy nitrogenous fertilisers which would otherwise go to make grass and milk. The minnows in the lake may be eaten by worms inside them as well as pike outside them.

Finally bacteria, which are of great importance not only in causing diseases, but in bringing about all kinds of chemical transformations which we are apt to lump together as decay, are of great importance, especially in the soil. At present the only students who study them seriously are students of medicine, but every biologist should know something about them. These are some of the reasons why a course in biology could be something much more than a combination of a course in botany with one in zoology, and why I, for one, hope that we may be able to start such a course in London.

I should like to see many of the future teachers of biology in secondary schools go on to do a couple of years of research. Only those who have done research can really understand how science grows. They also acquire a standard of accuracy which is impossible in the more hurried work for examinations. Above all they may learn intellectual integrity, that is to say the habit of examining a theory and trying to disprove it before you adopt it, particularly if it is a theory which you find satisfying.

Science grows so quickly that refresher courses are absolutely necessary. Many schoolmasters are still teaching what they learned about 1910, though some of it has been proved inaccurate, and much of it can now be presented in a simpler form. Of course, history and other branches of knowledge are progressing too, but it is much easier to keep up with their progress by reading books and journals, whereas science cannot be taught without demonstrations and experiments. Ideally every school science teacher should come back to the university for a term every five years or so. There are not yet enough teachers, or enough accommodation in the universities, to make this possible. But if education is to develop along the lines laid down in the recent White Paper, we should reach this stage in the next twelve years.

I have written about my own subject, but if I were a historian or a linguist, a geographer or a physicist, I could make out a similar case. We shall only get the educational system that our children deserve if the universities play their part. And this will only be possible as more and more voters realise that first-rate secondary education for their children is not a luxury, or, as Sir Herbert Williams said in the House of Commons, a waste of time, but an essential preparation for citizenship.

WOMEN IN SCIENCE

IN 1942 THE NAZIS WERE PUSHING WOMEN INTO factories as feverishly as they pushed them out in 1933. But they were certainly not using women in their war effort as well as Britain, let alone the Soviet Union. As more and more women came into industry the question came up of how far they could do a man's job.

The record of women in science has a big bearing on this question, because research is more and more becoming a matter of skilled manual work. This is obviously so in physics and chemistry, where everything depends on very accurate weighing and measurement. It is also the case even in such non-experimental branches of science as classificatory zoology. Linnaeus, the great Swedish classifier of the eighteenth century, looked at a number of animals and decided that the lion, cat, leopard, tiger, and so on, were like enough to be put together in the genus *Felis*, while dogs, bears, weasels, and so on, were put in different genera. If a modern zoologist wanted to improve on Linnaeus, he or she would probably count the chromosomes in the nuclei of cells of different cat-like animals, and if he found that they fell into two different groups, he might split the genus. But to count chromosomes you need to harden the cells with suitable chemicals, slice the tissues very finely, mount them under a microscope, stain them, and draw them or photograph them. All these are skilled jobs. At the present time my life depends on my skill as a chemical analyst. If I make a bad enough slip, I may very well be killed, and many others are in the same position.

Few women have so far made big scientific reputations. Women are obviously the equals of men on the stage, the screen, and the concert platform, and nearly if not quite so as writers of fiction. They were probably kept out of science, and still are, by their education, but in the last fifty years they have begun to compete in a big way.

The greatest woman scientist was probably Madame Curie, a Pole by birth. She succeeded in the monstrously difficult job of purifying and isolating radium, which was present in one part per six million of the material from which she started, that is to say one pound in 2,700 tons. It is hard enough to separate it to-day when its properties are well known, and the amount of it at each stage can be accurately estimated. Madame Curie combined the intellect of a first-rate scientist with the skill of a first-rate craftsman and the patience of a first-rate charwoman. Two other women have since done similar feats, namely Dr. Meitner, a German-Jewish woman who, with O. Hahn, isolated the radioactive element protoactinium, and Dr. Tacke, a German who collaborated with Noddack in isolating the rare element rhenium. The collaborators later married.

Other women scientists have also distinguished themselves by extreme technical skill. Miss Pockels was the first to get a surface of water so clean that its surface tension and the effect on it of very thin films of oil could be accurately measured. Dr. Stephenson was the first to determine the oxygen consumption, or in ordinary language, the breathing, of bacteria, when given different kinds of food. Dr. Ethel Brown Harvey managed to separate the nucleus from developing sea-urchin eggs, and induce the remainder to develop through several stages, which upset many theories on the subject. Dr. W. E. Brenchley has proved the necessity for plants of elements such as boron in quantities too small to be detected by the ordinary methods of analytical chemistry.

If I want a bit of tedious and difficult work to be done as accurately as possible, I should generally give it to a woman rather than a man. The French physicist Langevin said that men were better scientists than women because they were lazier. When faced with a problem of this sort they try to find a short cut, and are thus more likely to make a new discovery. This may be an inborn characteristic of the sex, but it may also be because women have traditionally been taught arts such as cooking, needlework, and housework, where there are no short cuts. Whatever the cause, it suggests that women are as well qualified as men to become good craftsmen.

Further, some women scientists bring intellectual as well as physical tidiness and conscientiousness into their work. My wife, with whom I am collaborating at present, has fewer original ideas than I, but she cleans mine up, and not merely makes them more precise, but suggests experiments of which I had not thought to check their accuracy.

One weakness of the Nazi war effort was their decision that women were only suited to be the recreation of the tired warrior, or the mother of Nordic blondes. Whereas the experience of Britain, and still more of the Soviet Union, has proved that women are fitted to be men's comrades and colleagues both in peace and war. Women did not play their full part in Hitler's plans for total war, and science will not reach its full stature till women are allowed and encouraged to use their special abilities to the full both in research and teaching.

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THE BACK DOOR TO SCIENCE

MOST OF THE MEN AND WOMEN WHO ARE ENGAGED in scientific research get university degrees in science. It is sometimes thought that this is necessary. This is not the case. I only got a scientific degree this year, an honorary one from the Dutch university of Groningen. However, I had an Arts Degree at Oxford, and it is certainly hard to get a paid research post without a degree of some kind. In consequence thousands of men and women who could do good research work are doing other things because they could not afford a university education.

Scholarships are better than nothing, but they certainly do not pick out the best future research workers. Even university honours examinations do not do so. A good many people who get first classes show no originality, and others who get lower classes do highly original research. Scholarships select children for precocity. The child who gets into a secondary school as the result of an examination at the age of eleven, may have grown up mentally quicker than the average. It does not follow that he or she will go on doing so. They also select for home environments where intellectual work is fairly easy. An only child has much better chances of doing home work than one with half a dozen brothers and sisters, but that does not make him or her a better research worker.

Now there is an opening into scientific research for those who have been unable to get scholarships, but feel the pull of science. This is by becoming a laboratory technician in the right kind of laboratory. In many laboratories there is no great future for technicians. At best they may hope to become head technicians supervising routine work, or perhaps constructing apparatus with which others will carry out research. At worst they will find themselves in poorly paid posts doing semi-skilled work. This was the case until fairly recently, in most university laboratories. The change which is now taking place is very largely due to the Association of Scientific Workers, which includes technicians as well as university graduates, and has fought their battles in many places.

At University College, London, for example, our junior technicians not merely have the right to education, but are compelled to put in at least eight hours a week in various classes. I think that some of our young ladies who hope to marry as soon as possible resent this considerably. These classes include lectures and practical work. We hope to give the technicians a thorough grounding in several branches of science and in mathematics. In our chemistry department a substantial fraction of the technicians ultimately get degrees. It takes them a good deal longer than the ordinary student to do so. And I have little doubt that in the examinations their practical work is better than the average, and their written work worse.

A few of the more ambitious technicians go to evening classes at a Technical College or at Birkbeck College. This year one of them got the best first class of his year in London University in his subject, and was immediately appointed as a university lecturer. This, of course, leads to us losing many of our best technicians. In the Soviet Union, where technicians have, I am told, a higher status than in University College, such loss is a real handicap to senior research workers. However, even from a selfish point of view, it will probably be worth our while to get ambitious and intelligent young men and women, who will try to reach a very high standard in their work.

Meanwhile thousands of boys and girls who want to take up science and would normally be able to join a university as students are kept out by the flood of ex-Service men and women, who are quite rightly given priority. If any of them read this, I recommend them to think seriously about taking a post as a technician. Of course, there are still many institutions where the technicians have no chance. But there are others where they have. The Association of Scientific Workers should be able to tell them what to expect in any particular case.

I recommend it for the following reasons. I learned much of my practical science by "bottle washing" for my father. Washing laboratory glassware is a highly skilled job. It is one thing to make glassware clean enough for ordinary chemical analysis, and quite another to prepare it for bacteriological work, where a single bacillus left behind may falsify an experiment. I went on to make standard solutions, calibrate apparatus, and so on, reaching a far higher standard of accuracy than is demanded in a teaching laboratory or in many industrial ones. In fact I learned a good deal of science as an apprentice rather than as a student. Scientific research demands manual skill as well as thought. So it is very important that a number of the recruits to it should be primarily qualified by their skill, even if they find the theoretical side of science difficult or dull.

There are no vacancies for students at present, but a fair number for technicians. Some of our best technicians will be satisfied with turning out skilled work. It is very pleasant to make really good microscope slides, to grow really good crystals, and above all to make really accurate apparatus. Naturally a professor is delighted to get a man or woman with no further ambitions. But we also realise that many of our helpers will want to discover something for themselves, and that it is our duty both to the technicians and to science to help them on their path. I cannot set up an employment bureau. Above all, I don't know whether Professor Smith gives technicians a chance, while Professor Jones does not. I only know that among my colleagues there are men who have started as technicians, not as university students, and have made good. I write this article because I want to see more of them.

SOVIET SCIENCE

I DO NOT KNOW AS MUCH AS I SHOULD LIKE TO KNOW about Soviet science. This is the result of an "iron curtain", to use Goebbels' phrase. But it is not an iron curtain of secrecy, but mainly one of linguistic difference. Most Soviet science is published in Russian, but a good deal in Ukrainian, Uzbek, or even one of the Caucasian languages. I can read scientific papers in ten languages, but none of these are Slavonic. The Academy of Sciences publishes its *Comptes Rendus* in English and French, but these are short summaries, not giving all the details which I often need. So my sketch of Soviet science is based on very inadequate knowledge.

After the Revolution, Soviet research started with a depleted personnel and a terrible shortage of equipment. It was handicapped in another respect. Lenin's programme called for an immense expansion of science. This meant that the ablest scientists had to spend at least ten years very largely on ordinary teaching and on the training of research workers. A physicist could not specialise in one small branch of his subject. He had to supervise research in many different branches. New universities were founded not only in Russia, but among nations which were almost wholly illiterate, and had no secondary education. It is not surprising that the first scientific papers from Turkmenistan were of uneven quality. Some were up to the best standards of Western Europe. Others fell below them. A very similar phenomenon occurred in the United States forty years ago. The quality of the publications from new Middle Western universities was not always high. Now they compare very favourably with those of Europe.

Laboratory equipment was very scarce for many years after the Revolution. It could not be bought in quantity abroad, and only during the second Five Year Plan was it made on any scale at home. This was one reason why some of the most conspicuous advances of Soviet science have been in the outdoor sciences of geology, zoology, and botany. The other reason was that these sciences were specially needed for the development of the country.

Soviet geology has been particularly fruitful. To take one simple example, as the result of the work organised by Obruchov we now know the approximate extent of the areas covered by ice in Siberia during the recent Ice Ages, though the analysis of the successive glaciations is not yet as complete as in Europe and North America. But it is quite sufficient to negative any suggestion that the position of the earth's poles has shifted much during the last half million years.

The tectonic structure of northern Asia has also been elucidated. In the course of this elucidation the Karaganda and Tungus coalfields were discovered, and the Kuznetz coalfield mapped. Without these discoveries the Soviets could not have overcome the Germans as they did. From the point of view of pure science, however, the Union is far better mapped geologically than any other area of equal size, though probably few parts of it are as well mapped as are the countries of Western Europe.

The Soviet Union can claim to lead the world in the study of soils. Such Russian words as chernozem and podsol are part of the international vocabulary. It is only fair to say that Glinka's pioneer work was largely done before the Revolution, but it has been carried on enthusiastically.

Again the fauna and flora of the Union are very extensively known. In fact, no other mainly uncultivated area of the globe has been as well studied as Siberia. The only data on variation based on literally millions of wild animals come from the Soviet Union, where the fur industry is so organised as to yield data in several respects more complete than that of Canada. The study of fish has been particularly full.

Animal genetics has been largely, though not wholly, confined to animals of economic importance. For example, the first data on autosomal linkage in poultry and the only data on linkage in sheep are due to Soviet workers. And they were the first to study gene distributions in natural populations, though here the Americans have possibly overtaken them.

It is widely believed that plant genetics in the Soviet Union came to an end with the death of the geneticist Vavilov, who had done very fine work on the origin and geographical distribution of cultivated plants. I do not know how Vavilov died, nor do I know how tens of thousands of other refugees from Leningrad died. As his institute at Detzkoë Seloe became a battlefield throughout the siege of Leningrad, it is not surprising that no research has been done there in recent years. I have little doubt that Lyssenko's attacks on certain genetical conceptions have slowed down the progress of Russian plant genetics. But such episodes are unfortunately common. To take one example, Cuénot discovered multiple allelomorphism and described a lethal gene in France in 1905, but as genetical ideas did not commend themselves to certain leading French biologists, French genetics are almost a blank between 1905 and 1935. But Soviet plant genetics are far from a blank since Lyssenko became a leading biologist. I need only mention Zhebrak's synthesis of octoploid wheats and Shmuck's work on the effects of different organic compounds in producing polyploidy. There can be little doubt that some Soviet plant breeders had under-estimated the importance of environment. Lyssenko, who has produced most conspicuous results by changing the environment of plants, has probably swung the pendulum too far in the other direction, but I do not doubt that it will settle down.

In the same way I have little doubt that British plant genetics will survive the fact that our leading plant geneticist, Harland, has had to take a post in Peru, with excellent effects on Peruvian agriculture, after dismissal on grounds which a British jury found unjust. There is, however, the important difference that Soviet plant genetics are likely to have a considerable slant in the physiological direction, whereas no such advantage will occur from the Harland case. I have only emphasised the Vavilov-Lyssenko controversy because it has been made the basis for attacks on the whole Soviet scientific system. My sympathies in the controversy are on the whole with Vavilov, but I respect Lyssenko's work and think that some of his criticisms were justified.

So far I have dealt with some of the outdoor branches of Soviet science. I know less about the indoor branches. Research is planned in the sense that the amount of effort to be devoted to different branches of research is a matter of policy rather than of chance. It was decided, for example, that so many thousand million roubles were to be devoted to geology and a smaller sum to organic chemistry, whereas in Britain organic chemistry is better subsidised than geology. But no planning commission can determine whether a given mountain will contain tin, copper, or just plain granite, or whether a new compound will be an insecticide, a useful drug, or a mere addition to the list of naphthaline derivatives.

The phrase "socialist science" has been violently criticised. And it is clear that if scientists reached one set of conclusions in a socialist country and another set on the same subject in capitalist countries, something would be very badly wrong with scientific method in one country or in all. But this is not the case. On the other hand scientists in a socialist country will investigate a rather different set of problems than those in capitalist countries, and in so far as they are Marxists, will tend to lay more emphasis on problems involving change. This is particularly notable in Soviet chemistry.

Soviet chemists have investigated chemical reactions, notably in gaseous systems, where Semenov's work on "chain reactions" has been universally accepted. Kharitonov has made remarkable steps in the study of changes in solids, such as the detonation of solid explosives. They have also played a leading part in mineralogical chemistry, particularly in the study of the processes by which minerals are formed. Vernadsky and his school have particularly stressed the concentration of rare elements by plants and animals. In organic chemistry they have made less spectacular progress. In a recent volume of British Chemical Abstracts, twenty-five per cent. of the citations on mineralogical chemistry, but only twelve per cent. of those on organic chemistry, related to work done in the Soviet Union. The chemistry of a socialist England or France would probably show the same concentration on change, but less on mineralogy, since mineral production is relatively less important.

In physics the Soviet Union leads the world in the study of great cold. This is largely due to the emphasis laid on gas liquefaction both in connection with the use of natural gas resources, and with the underground gasification of coal. As a result they have produced by far the best data on such matters as the boiling points of mixtures of liquefied gases, and also by far the most efficient methods for the liquefaction of helium. It is probable that Kapitza, who designed the apparatus in question, and also studied the properties of liquid helium, has now switched over, as a pupil of Rutherford, to the physics of atomic nuclei. In this, which was until recently the most "highbrow" field of physics and is now a very practical one, Soviet workers have so far published comparatively little, though to take one example, they first showed that "cosmic rays" consist mainly of particles.

Another branch of physics where Soviet workers rank very high is the physics of the solid state. Yoffe and his colleagues have shown that rock salt crystals are considerably stronger than steel if they are prevented from forming cracks at the surface. Unfortunately, the only method so far found of doing so is to keep on dissolving this surface, so the strength does not last very long. I mention this as a typical example of fundamental research which has found no application, because many people honestly believe that no fundamental research is done in the U.S.S.R.

Soviet biochemists have recently made two fundamental discoveries. Engelhart and Lyubimova have found that the same muscle protein which (as had been shown in Britain and America) liberates energy by catalysing the breakdown of a certain unstable compound, also changes itself in the process, and is responsible for the contraction of the muscle. I can imagine no discovery in pure science which would have pleased Marx more. Braunstein showed that another enzyme is responsible for interchanges of atoms between proteins of the living substance, so that they turn out to be a good deal more alive or at any rate less static than had been thought.

Physiologists have specially investigated the acuity of the human senses, for example, the smallest number of quanta which the eye can perceive, and the influences which raise or lower sensitivity. There is no doubt of the achievements of Soviet surgeons, notably Filatov, who has successfully saved many eyes by grafting corneae from the dead to the living. On the other hand the remarkable claims made by Bogomoletz for his antireticulocyte serum are still under investigation. In any case there has been solid progress in the diagnosis, prevention, and cure of a number of diseases, particularly of those prevalent in the Asiatic parts of the Union, together with great strides in industrial hygiene, notably that of anthracite miners.

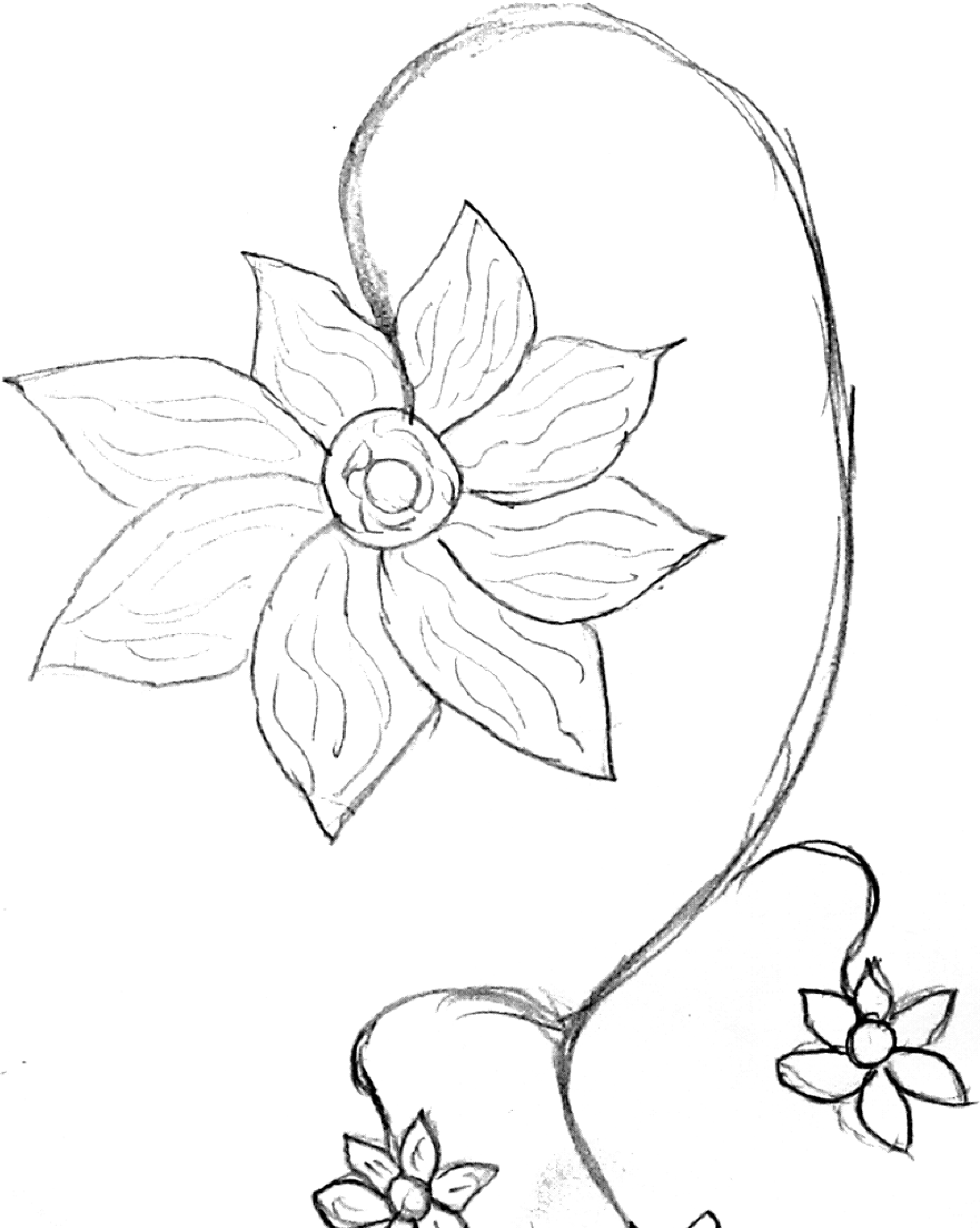
Science plays a bigger part in Soviet education than in that of any other country. The full results of this fact will not be seen for another generation. The quality of Soviet science is still uneven because in the immense expansion after the Revolution there were responsible jobs for everyone with a scientific training. The majority of the younger generation will not get so far, but the standard of the picked few will be higher.

Within the last few years there has been a considerable separation between the universities and the research institutes. Many foreigners regard this as a backward step. It would certainly be so in most countries. In England the gap is between academic science on the one hand and industrial and military on the other, the latter two being more or less secret. In the Soviet Union the tendency is to associate a good deal of pure or fundamental research with industry or war. For example, the Academy of Military Medicine before the war was working on chemical changes in developing eggs. The same man cannot do pure research, teaching, and application at all thoroughly. Only time will show whether the Soviet policy is correct. It may or may not lower the standard of teaching. It will tend to bring research nearer to practical problems. This has its dangers and its advantages. As the scientific level of the average citizen rises I think that the advantages will outweigh the dangers.

It is impossible to predict the future, but judging from the quality and quantity of the work so far done, and the solid preparations made for future work, it is entirely possible that a generation hence the contribution of the Soviet Union to many fields of science will be as obviously greater than those of any other country as are those of the United States to-day.

PART IV

SCIENCE FOR SOCIETY



AVERAGES

YOU CANNOT GET FAR IN ECONOMICS OR POLITICS without using statistics. And you cannot get far in statistics without using an average—for example, the average wage of a woman in the engineering industry, or the average age at death of an anthracite miner.

Now an average has two functions. First of all, it is representative. It gives one an idea of the size of a fairly typical member of the group and makes a comparison between groups possible. One can say at once that, on the whole, women in the British engineering industry get less pay than men, but a very great deal more than men in Indian industry. Similarly anthracite miners on the whole do not live so long as other coal miners, but live longer than slate quarriers. Secondly, the average tells you exactly what share each individual would get of money, land, or any commodity which can be divided up, if it were shared out equally.

Now, when you know the average, you can answer the second question exactly. But the average is not necessarily representative.

Suppose there are two villages, each with twenty families. In the first village one family has an income of £10,000 per year, and nineteen have an income of £150. In the second village ten families have an income of £300 and ten of £200.

Then the average family income in the first village is £642 10s., in the second it is £250. Yet on the whole the people in the second village are richer. If you pick a family at random from each village, it is nineteen to one that the family from the second village will be richer. We can only say that the first village would be richer if the incomes were divided evenly; but that is a big "if".

How can we choose a representative value so as to get over fallacies of this kind? Instead of the average we choose what is called the median. If you stand 101 men in a row and measure the height of the middle man, you get a height which is often more representative than the average. There are as many taller than the median height as there are shorter than it. In the first village the median income would be £150, in the second between £200 and £300. It is impossible to compare real wages in Britain and the Soviet Union very accurately. The average productivity of labour is less in the U.S.S.R., so the mean real wage is lower. But incomes are much more evenly distributed, so the median, if it is lower in the Soviet Union, is not much so.

And long before the mean income in the Soviet Union exceeds our own, its median will have done so unless we change our economic system very quickly indeed.

Another advantage of the median is that it enables you to give a representative value for qualities which cannot be measured, but which can be put in order. I am probably less musical than most of my readers, and better at mathematics. But there is no sense in saying that I am half as musical as you, or three times as mathematical.

Sometimes, but not always, the mean, or average, is roughly equal to the median. This is so for heights of human adults, but it is not so for weights. The average weight of Englishmen about 1880 was 156 pounds. But the median was only 147 pounds. This is because in a sample of 8,000 men there were some very fat ones. Ten weighed over 250 pounds whereas none weighed under 90 pounds. So the fat men helped in the average. but each counted no more for the median than if they had weighed only, say 200 pounds.

In the same way very rich men have a large effect on the average income, but very little on the median. If we keep these distinctions in mind, we shall avoid being taken in by arguments about averages.

When we have determined our average, or our median value, we next want to know something about the spread round it. Clearly, for example, the spread of human weights is bigger than the spread of heights. Quite a number of people weigh half as much again as the average, that is, over 234 pounds. But the average male height is about 5 ft. 8 ins., and a man who measures 8 ft. 4 ins., can make a living as a giant in a circus.

Probably the best measures of the spread are by means of what are called the quartiles. If we measure the twenty-sixth man from the top and bottom in our row of 101 men arranged according to height, they will give us the upper and lower quartiles. One-quarter of the heights exceed the upper quartile, one-quarter fall below the lower quartile. In this case the quartiles are about two inches above and below the median.

The difference between quartiles, divided by the median, gives a fair idea of the spread. This is only about six per cent. for heights, but probably over a hundred per cent. for incomes of English adults. The total range does not give such a good idea. A sample of a thousand people might happen to include a dwarf or a giant, but probably would not. So the range which includes the middle half or the middle four-fifths of the population is more useful.

There is only one case where the extremes matter, and that is when they are socially valuable. One Newton is worth a thousand schoolteachers with mathematical degrees, one Beethoven worth a thousand men who can improvise on the piano. It may be that in such cases a high range of attainments is more important than a high average.

Of course, statisticians have devised a number of other ways of picking out a representative on the one hand, and measuring the spread round it on the other. But if we understand the meaning of an average, and the false conclusions which can be reached by using it wrongly, we shall have made a good start in understanding statistics.

ARE THINGS WHAT THEY SEEM?

DURING A DISCUSSION ARISING FROM AN ARTICLE I wrote on the late Sir Arthur Eddington a reader remarked that things are not what they seem. There is, of course, some truth in this statement, but I believe it would be a good deal truer to say that things are what they seem and a great deal more as well.

Everyone knows that one can be deceived by appearances. One reason why, even in the days of personal rationing, smash-and-grab thieves do not raid sweet shops was that the objects in them which looked like chocolates were often dummies made of sealing wax. Our ears can deceive us, as when we take a rattling window for a distant bomb, our tongues when we take saccharine for sugar, and so on.

We only know about things through our senses. These senses include not only sight, hearing, touch, smell and taste, with minor senses such as that of temperature, but the very important muscular sense. This tells us, for example, that it is harder to lift a chair than a feather, and a great deal of our knowledge of matter comes through it.

Each sense gives us a different kind of information about matter. What kind of information it will give depends on the structure of the sense organ. Thus our ears respond to vibrations in the air with frequencies from about 30 to 30,000 per second, and each frequency gives its own sensation. Our eyes respond to electro-magnetic vibrations with frequencies of 15 to 30 thousand million million per second. We do not feel these as vibrations, but as tones or colours. At first sight this seems to prove that our senses deceive us. We see a vibrating string, and hear a steady musical note. How can both senses give us correct information? In the nineteenth century there was no answer.

In the twentieth century, physicists, notably Planck and Einstein, found that radiant energy was taken up and given out by matter, not continuously, but in packets called quanta, whose size is proportional to the frequency of the vibration. So long as it is travelling, light behaves as a train of electro-magnetic waves; but it is emitted and absorbed as units called photons, and those of violet light are twice as big as those of red light. As the Soviet physicist Frenkel pointed out, the same is true for sound.

Physicists who have no knowledge of dialectics are troubled by this contradiction in the properties of matter. But the contradiction is not really a new one. It is already there when we see a piano string vibrating and hear a steady note.

It is as intelligible that energy packets of different sizes should have different properties as that pennies should differ from half-pennies, though, of course, we do not yet know why they have the particular qualities which we perceive.

We can only perceive one octave of electromagnetic vibrations directly. The wavelength of the reddest light we can see is only twice that of the deepest violet. We have to use apparatus to translate the others into forms of energy which our senses can pick up. For example, we translate X-rays, which have a higher vibration frequency, into light with a fluorescent screen or a photographic plate. We translate radio waves with a lower frequency than visible light into sound with a radio-receiving set, or into light with the apparatus used by bombers for bombing through cloud.

If we had a more complete set of sense organs we should perceive X-rays and radio waves directly, and they would give us sensations of a kind which, of course, we cannot imagine. Other animals certainly perceive things which we cannot. For example, bees can distinguish colours in the ultraviolet, and bats guide themselves by using sound waves too short for us to hear, which are reflected from objects around them, like the light from a car's headlamps.

Probably no animal has a much bigger range of senses than ourselves. For example, dogs can distinguish more smells than men, but are colourblind. But if we had all the senses of other animals, we should perceive directly a good many things and processes which we only know indirectly through special apparatus.

In fact, we only appreciate a tiny fraction of the qualities which there must be in the world. Physicists learn about the existence of radio waves as a blind man, by doing experiments in which the heating effect of light is used, could discover that something came from the sun which was reflected by a polished surface and concentrated by a lens. But, of course, they do not know what quality they would find in these waves if they perceived them directly.

A baby gradually learns to fit its various sensations together. They tell it a rather contradictory story. There are things that one can see but not touch, like the sun or an image in a mirror. There are others that one can feel but not see, like the heat in a hot plate. Adults take these contradictions for granted, and build up a picture of the world which works fairly well.

But further study shows new contradictions. Eddington did not believe in the reality of solid objects because, when investigated by physicists, they turned out to consist mainly of empty space of which only a tiny fraction was occupied by rapidly moving particles. If he had possessed an ultra-microscopic eye with which he had perceived these particles ever since he was a baby, this contradiction would have affected him less. The universe is certainly queer. There are doubtless more things in it than are dreamt of in any philosophy. But that does not mean that it is not real, or that the scientific account of it is not true as far as it goes, and is not in fact the nearest approach to truth which we can make at the present time.

SHAPES AND WEIGHTS

BIOLOGY HAS BEEN VERY LARGELY A MATTER OF cataloguing shapes. The botanist must be able to distinguish wheat from barley, the zoologist must know ship rats from sewer rats. The geologist can date a rock from the shells in it, and use his knowledge to predict whether coal or oil will be found in it. And comparative morphology is essential for the study of evolution.

But animal shapes, as well as their sizes, change with time. All the parts of a human baby are smaller than those of an adult; but the trunk grows quicker than the head, and the limbs quicker than the trunk. In different words, if the baby were six feet long, it would have an enormous head and very short arms and legs.

In fact, the growth rates of various parts of the body are different. The laws of relative growth are, moreover, very different in different animals.

For example, a baby horse has long, thin legs. Its trunk subsequently grows quicker than its legs. This is clearly an adaptation. For in wild life it may have to start running the day it is born. But its food is milk, which is much more easily digested than grass, so it can carry on with a smaller digestive apparatus.

Georges Teissier in France and, independently, J. S. Huxley in Britain, measured and weighed different organs of a great many animal species, and arrived at a general law which they describe as allometry.

Suppose a crab weighs an ounce and one of its claws weighs one-hundredth of an ounce, then if the claw and the crab grow at the same rate, when the crab weighs two ounces the claw will weigh a fiftieth of an ounce. But if the claw grows twice as fast as the crab, which is the case in some species, then it will weigh one twenty-fifth of an ounce, and so on. In fact one can calculate that if the crab, apart from its claws, could reach a weight of a hundred ounces, the claw would weigh a hundred ounces, too. Actually, the crab does not grow to this size.

On the other hand, the brain grows more slowly than the rest of the body. If you weigh the brains of cats of different ages, you find that a kitten's brain weight is a bigger fraction of its total weight than a cat's. What is more, the principle applies to different closely related species. For example, a lion's brain is bigger than a cat's, but is a much smaller fraction of its total body weight.

The laws followed can be stated mathematically, and are followed with considerable precision. Again, women, on an average, have smaller brains than men. But their brains are not small compared with those of men of the same stature. The rich on an average, have larger brains than the poor. But their bodies are even larger in proportion, presumably because they are better fed and have less crippling diseases, such as tuberculosis.

On the whole, Teissier worked with small animals, and even with single cells, while Huxley interested himself especially in large animals. For example, he showed that the antlers of deer grew more than proportionately to their body weight. British red deer are poor creatures compared with those of the Carpathians. They seldom have more than a dozen points on their antlers, compared with twenty or more in the Carpathians. This is not because they are a degenerate race, but because they are badly fed. When the Duchess of Sutherland, and other Scottish landowners, evicted men, women and children to make room for deer they did not even put the deer under good conditions. When Scottish red deer are let loose in New Zealand, their body weight doubles and the weight of their antlers is more than doubled in two or three generations.

There is nothing surprising about the principle of allometry. Every engineer knows that a model may give very misleading results. If you tried to argue from a scale model of a building to the full-scale building, you would have plenty of accidents. For when you increase your linear dimensions tenfold, you increase weights a thousand times. Hence each square inch of brick or concrete must bear ten times the weight which it does in the model. Similar but more complicated principles hold for ships and aeroplanes.

Teissier has worked on a number of other biological problems. For example, he has worked with l'Heritier on inheritance. In the fly *Drosophila melanogaster*, which was supposed to be the perfect example of inheritance according to Mendel's laws, they discovered a character which has inherited quite differently.

Teissier's work had prepared him to accept Marxist theory. He has shown how quantity changes into quality in animal growth. A large animal is not just an enlargement of a small animal of the same species. Some of its parts are relatively bigger, and others relatively smaller, so that its shape is different. Human organisations follow similar laws. A group working on a job will naturally choose one of their number to organise the work. This happens in collective organisations in the Soviet Union. The crew of a Soviet fishing boat have to obey their skipper; and the discipline at sea is probably as good as under capitalism or better, though the laws forbidding exploitation of the crew are stricter.

But when an organisation gets larger, its head may easily develop into an absentee landlord or financier quite out of touch with the workers. In fact, large human organisations always lead to oppression unless there is a democratic machinery to prevent it.

We must always be careful of arguing from biology to politics and economics. But I do not think it is hard to see how Teissier's biological work led him to the view that the time is ripe for a radical change in the structure of French society.

BLOOD DONORS IN THE FUTURE

BLOOD TRANSFUSION IS NOW FAMILIAR TO EVERYONE. At first the transfusions were always of whole blood. The obvious idea, if a man has lost a quart of blood, is to give him a quart of someone else's. In a great many cases this obvious idea is correct.

But it is often sufficient to make up the volume with plasma, the fluid part of the blood which remains after the red corpuscles have been spun off. This is easily done in a centrifuge, as the corpuscles are considerably denser than the plasma. Provided the volume is made up to normal, it does not much matter that there are fewer corpuscles than usual in a pint of blood. If the blood is diluted in this way, the patient gets short of breath if he takes exercise, but is quite comfortable when at rest. For we do not need the full oxygen-carrying power of the blood except when we are working hard. But we do need the full normal volume of blood. If this is reduced, the blood stagnates in the veins of the lower part of the body, and not enough is returned to the heart to allow it to pump blood up to the head. It is not enough to make up the blood volume with water, or even with a mixture of water, salts, and sugar. This leaks out of the bloodstream unless it is accompanied by the large molecules found in the plasma, which cannot leak out through the blood vessel walls, and hold back the water and salts.

Blood plasma will keep much longer than whole blood, and can be dried or frozen. The British and American armies have used dried plasma on a large scale, dissolving it in water when needed. The Red Army, for obvious reasons, made more use of frozen plasma. Even the dried plasma is prepared by first freezing it and then removing the water in a vacuum, since the plasma proteins are unstable when dried above freezing point. But the Americans have gone a great deal further than this. So perhaps have the British and Russians, but if so they have not told the world. The plasma contains a great many different proteins, and Professor Cohn of Harvard, and his colleagues, have worked out methods for separating them on a vast scale.

About half the proteins of plasma are called albumin, from their resemblance to the main protein of egg white. They can be separated and made into a strong solution, each pint of which, on injection, will cause an increase in blood volume of four or five pints. This has proved particularly valuable in treating shock and burns, which cause a big loss of fluid from the blood. Another fraction consists mainly of fibrinogen, the very sticky protein which coagulates to form blood clot. It clots on combination with another protein, thrombin, which is formed when blood comes into contact with damaged tissue cells, and can also be purified. Once fairly pure fibrinogen is available, large artificial blood clots can be made. One form is a strong, elastic sheet, which is particularly useful in covering the brain surface after an operation, to prevent it sticking to other tissues.

Another form used is a spongy structure which is soaked in thrombin solution, and instantly controls bleeding even from an organ such as the liver or kidney which contains very many blood vessels. These artificial clots have mechanical properties like those of rubber or sponge, with the immense advantage that if they are left in the body they are gradually invaded by cells, and removed or replaced by scar tissue, like a natural clot.

Another fraction, called the gamma-globulins, contains the anti-bodies which are responsible for immunity against certain diseases. This fraction is about twenty-five times as effective as whole plasma or serum. It has been used in the prophylaxis of measles, and striking results are claimed. Of 2,000 children in New York and other cities who were injected with a gamma-globulin concentrate after exposure to measles only 600 developed any symptoms at all, and only sixty got what was described as an average attack of measles. The results on mumps, influenza, and other diseases, look hopeful. But a lot more will have to be done in checking results before such methods can be recommended for universal adoption.

Above all, these substances are beautiful media for bacterial growth, and a number of people have been killed by the injection of infected sera. If they are properly prepared and properly used the danger is very small. But the danger of infection is vastly increased if they are administered by a general practitioner in the intervals of his other work. Asepsis is far easier at a hospital or a health centre than in a doctor's surgery.

Other fractions include some of the hormones and other substances which help to regulate the body's activities. They have not yet been concentrated sufficiently to be of practical value, but they probably will be.

Blood donors can look forward to a rather different field of usefulness in the next generation. There will always be a demand for whole blood to deal with accidents and anaemia. But specially qualified people will be wanted to provide particular substances. When we next have a severe epidemic of influenza, then if our medical organisation has developed sufficiently, those who get it in the first month, and recover, may be able to save a good many lives by providing anti-bodies for the rest of the population. Sufferers from haemophilia may be kept in health by weekly injections from suitably qualified donors. Probably as time goes on we shall rely less on horses to protect us against diphtheria and tetanus, and prefer to get our antitoxins from our own species.

We may go much further and deal with other organs as we do with blood. Doctors and experimental biologists in the Soviet Union have led the way in the study of grafting in plants, animals, and men. The latest news of this work deals with the experiments of Professor Sinitsin. He had already succeeded in removing a frog's heart and transplanting that of another frog. The combinations lived for over six months, and became fathers and mothers. He has now grafted the heart of one dog, cat, or rabbit onto the neck of another, and joined them up with the circulatory system, so that one dog has two hearts working. The conditions for successful grafting in men will doubtless be at least as complicated as those for successful blood transfusion. When they are mastered there seems no reason why a heart from a person who has been killed accidentally, or died from a disease not affecting the heart, should not be grafted on to a patient with severe heart disease. It would then take over the work of the sick heart, which could be removed if necessary. This is some way in the future; but it is not an idle dream, though some people may think it a disgusting one. I have seen enough young people dying of heart disease to relish the prospect that if I die, say of a cerebral tumour or a street accident, my heart will go on doing a job after I am dead.

DEFECTIVE OR DEAF?

A GREAT MANY CHILDREN ARE CERTIFIED AS MENTALLY defective, sent to special schools, and often deprived of a good deal of liberty throughout their lives. Many people think that the proportion of defectives is increasing, and that our average intelligence is declining too. Some also believe that mental defectives should be sterilised, as many have been in Germany.

Now I have no doubt at all that there are genuine mental defectives for whom there is no cure in the present state of our medical knowledge. But I have also no doubt that the children in special schools and the adults in institutions include a number whose defect is not mental, but sensory. This is strikingly brought out in a recent article in the British Medical Journal by Dr. Mary Sheridan, assistant School Medical Officer in Manchester.

Everyone knows that blind children cannot learn to read, but extreme short sight or astigmatism may make reading very difficult and yet not be noticed without a medical examination. One of Kipling's best short stories is an obviously autobiographical account of a boy at a boarding school treated as a mental defective because he needed spectacles. It is easy to detect total or almost total blindness, but testing for short sight, astigmatism or colour-blindness is a skilled job. Similarly it is easy to detect total deafness. But only in the last few years have methods been invented for measuring partial deafness.

Total deafness has long been known to be a cause of mental defect. The minds of deaf and dumb children do not develop unless they are taught to speak with their fingers or to read the lips of speakers, and finally to speak themselves. A man may keep his mind on a desert island or in solitary confinement, but he can only develop it in society. Hearing differs from sight in many ways. We cannot estimate the direction from which a sound comes with much accuracy. A dog can do it far better. But we can distinguish vastly more sounds than colours. And we can also distinguish and remember complicated sound patterns in time, for example, words, tunes, and Morse phrases, whereas visual patterns must be spread out in space. The modern audiometer is an instrument which produces a great number of pure tones, each at a series of graded intensities. Your hearing may be quite good at one end of the musical scale, and bad at the other. The most usual defects are at the high end. Some people have never heard a bat's squeak. Others can hear it as children, but become deaf to it in middle life. This sort of deafness may be inborn, or due to injury. Boilermakers become deaf to the notes made by a riveting machine, and aeroplane pilots to those of their engines and propellors.

In speech we use about 6½ octaves, 1½ being below the middle C of a piano scale, and about 5 above it. The very high notes, or rapid vibrations, play a small part in the vowels, but a big one in the consonants, especially S, F, and TH. A child who is deaf to high tones will not only tend to say F for TH, or TH for S, Y for L, and so on, but may be unable to distinguish them when others say them. Defective speech is often due to malformed mouths, but inability to distinguish is usually due to deafness to high tones. Dr. Sheridan quotes the case of a girl certified as mentally defective and practically dumb. Her hearing appeared normal. She turned round when her name was called behind her back, and so on. But her hearing turned out to be "patchy", only some notes being heard. At a school for the deaf she was rated as very intelligent.

A child with defects such as this might appear normal in China. The Chinese depend far more than we do on vowels. The word which we transliterate as "ho" has a number of different pronunciations, with a different tone for the vowel. On the other hand Chinese do not easily distinguish our L and R. European languages, and especially English, include words with masses of consecutive consonants such as "sprints" which baffle Asiatics. Indians often say "United Estates" or "bockus", while some Europeans in India cannot distinguish the Hindustani words for horse and European. So a child which could not learn English owing to partial deafness might be able to learn Chinese, and vice versa.

Some cases of partial deafness can be remedied with special devices to amplify the high notes.

Other children must be taught lip-reading or deaf-and-dumb language. But they are no more mentally defective than if they were colour-blind, though they may become so if cut off from human speech; and it is very important that all allegedly defective children with speech defects should be tested in this way.

There is another moral to this story. Hearers of English make more mistakes with consonants than vowels. This means that a public speaker who finds that his voice does not carry will do better to get his consonants clear than to strain his voice by shouting. If I am generally audible at the back of a hall, I attribute this to the fact that, in learning to speak to my grandmother, who lived to be a hundred, and was hard of hearing rather than deaf, I had to take pains with my consonants.

LIFE AT HIGH PRESSURES

MEN GO DOWN TO CONSIDERABLE DEPTHS UNDER water for both peaceful and warlike purposes. As you go down the pressure increases. Suppose you have a vertical tube whose cross-section is a square metre, full of sea water. The amount of water in every ten metres of this tube weighs as much as would all the air in it if it went up, say to a height of fifty kilometres, above which there would be only a few milligrammes. This means that for every ten metres, or thirty-three feet, that we go down, we get an extra atmosphere's pressure. Thus the total pressure at the surface is one atmosphere, at thirty-three feet two atmospheres, at 330 feet eleven atmospheres, and so on.

Now a man can cope with this pressure in two ways. He can get into some kind of metal box which will resist the pressure, while the pressure inside the box stays at one atmosphere. The box may be a sphere, like that in which Beebe went down half a mile. It may be a submarine. Whether any submarines can dive more than about 500 feet without caving in is a secret. Or it may be an armoured diving dress with more or less flexible joints. Such dresses work well enough near the surface, but not so well at great depths. The reason is simple enough. The shoulder joint of a suit of armour must be a good deal broader than that of an ordinary greatcoat. I doubt if it could be cut down to an area of less than half a square foot. But let's suppose it has been cut to fifty square inches. At 330 feet, or an excess pressure of ten atmospheres, the pressure on the joint is 10 × 50 × 15 pounds, for an atmosphere is fifteen pounds per square inch. That makes 7,500 lbs., or about three tons, six cwt. Suppose by some miracle of lubrication the co-efficient of friction were cut down to one per cent., this would mean that the diver would have to exert a force of seventy-five lbs., whenever he wanted to raise his arm. And things would be worse at greater depths. There is no future in armoured dresses. There is a future in pressure-tight chambers where the diver can sit comfortably and operate machinery by electrical control. So far, however, such chambers have been most successfully used with a telephone to direct operators in the parent ship as to how to use a grab or where to place an explosive charge.

The other way to cope with pressure is to submit to it. In this case one must breathe air at the same pressure as the water outside. The reason is simple. Supposing a man with air at one atmosphere's pressure inside his lungs were suddenly subjected to water pressure at 330 feet, and suppose that on a life-size X-ray photograph his lungs cover half a square foot. At 330 feet he would have over three tons more of pressure on the outside of his chest than on the inside. It would be a quick death! The surprising thing is that balanced pressure is completely harmless, and is not even felt. Our tissues transmit pressure as smoothly and evenly as if they were completely fluid. They give way to an extent which can barely be measured. Actually your volume is reduced by about one twenty-thousandth for each atmosphere. But you don't notice this any more than you notice the fifteen lbs. pressure on each square inch of your skin in everyday life.

There are many different kinds of diving dress. The standard type is made of very heavy rubberised twill, and is made in one piece coming up to the top of the diver's chest. He gets in and works his hands out through the armholes. Then a breastplate is screwed into the upper edge of the dress, and his attendant gives him lead-soled boots and rubber bands round the wrists which should, but may or may not, keep the water out of his sleeves without stopping the blood flow into his hands. A steel helmet is screwed on, with an air hole, a telephone, and an exit valve for air. Forty pounds of lead are hung on his chest and as many on his back. A glass window is screwed into the front of his helmet. (I had to reduce my moustache from Kaiser Wilhelm's size to nearer Hitler's size because it used to get caught in the screw-thread.) Then he goes down a ladder for six feet or so, after which he usually transfers to a rope with a lead shot at the bottom. Meanwhile air is sent down to him. The air must be delivered at a pressure equal to that of the water round him. This is easily achieved with a pump if he is only down 30 feet or so. But if he is at 300 feet the air must be compressed to ten atmospheres' pressure, that is to say, into one tenth of its volume. This needs specially designed pumps, and either several teams of very powerful men taking spells on it, or better a small motor with its exhaust well away from the air intake. The modern tendency is to replace the pump by a battery of compressed air cylinders (bottles, the Navy calls them). If this is done, some other gas mixture can be used instead of air.

The hose pipe is armoured with wire spirals between layers of rubberised cloth, and goes to the diver's helmet through a non-return valve. This is an essential safety device. If the air-pump fails and the valve starts leaking backwards the water pressure forces the diver up into his helmet. His blood and much of his flesh go up the hose pipe, and all that is left in the dress are his bones and some rags of flesh. This has happened. But normally he gets a good stream of compressed air which inflates his dress until, in spite of the lead weights, his net weight is only a few pounds. He adjusts this by opening or closing the screw of the exit valve in his helmet, no more thinking about it than a cyclist thinks of how to balance his machine.

In warm water one can wear a dress coming down to the waist only. But the main other type worth mentioning is the self-contained. Here the diver takes his own air supply with him in steel bottles. The dress may be as described above, but the men who went into enemy ports during the war wore skinfitting dresses and breathed through a mouthpiece into a rubber bag which the Americans call a counter-lung because it expands when the lungs contract, and conversely. If the diver is supplied with pure oxygen and has a canister of soda-lime mixture in the counter-lung to absorb the carbon dioxide which he breathes out, it is obvious that he need not form any bubbles. It is also obvious that if you are trying to fix a time-bomb to the bottom of a German battleship you have a fair chance of dying anyway, but this is considerably increased if you produce quantities of bubbles. Even if there is no enemy near, compressed oxygen will last you about ten times as long as the same volume of compressed air.

The Davis submarine-escape apparatus is the simplest form of diving apparatus. It consists simply of a counter-lung with a small oxygen cylinder and soda-lime canister, and a mouthpiece. It is meant for getting out of a submarine, but has often been used to do a job of work.

My main job during the war was to tackle the physiological dangers to which divers and men trying to escape from submarines were exposed, apart from any enemy action. I didn't even try to tackle all of these. And I was only one of a number of scientists on the job, some under my direction, others taking orders from the Royal Naval Physiological Laboratory, an excellent institution established during the war, and the Medical Research Council. Apart from the Navy, we got invaluable help from Messrs. Siebe Gorman & Co., the well-known makers of diving dresses, and I certainly owe my life to the reliable nature of their products.

A lot of our work was done "in the dry" in compressed air, for many of a diver's troubles are simply due to the pressure, and you can give good imitations of them and find out how to prevent them, without going under water. Most of our "dry" work was done in Siebe Gorman's Chamber No. 3. This is a steel cylinder like a boiler. It lies on its side and is eight feet long and four feet in diameter. So three people can sit in it, but one can't begin to stand up. At one end is a steel door. This opens inwards and has a rubber flange, so once there is a good air pressure inside, it is extremely tight. There are some glass plugs in the side and in the door which act as windows, and, of course, inlets and outlets for air, but no lamps or telephone inside. One communicates by a code of taps, by shouting, or by holding messages to the window. This factory has no water more than twenty feet deep, so to simulate a dive we used a steel tank about six feet across and ten feet high. It had about seven feet of water in it, in which the diver could stand, sit, crawl, or lie. There was a pulley with a weight so that the diver could do measured amounts of work, and a slate to write on. Above this was an air space where the attendant sat on a shelf with his feet in the water. He kept an eye on the diver and could haul him or her up with a rope if he or she lost consciousness.

By letting compressed air into the air space, one could put any desired pressure on the water, and we were able to reproduce all the symptoms reported in genuine dives. There was one extra symptom. Divers are tough men, but some of them got a genuine claustrophobia in this tank. They longed for the wide-open spaces of the sea bottom. Certainly it was a queer experience to wait under water in this rather dark tank, knowing that one might lose consciousness at any moment, and perhaps wake up with a broken back, conceivably not wake up at all, and to look out through the very small window at butterflies, bicycles, and other familar things. My father called this tank the Chamber of Horrors. The Navy called it the Pot.

Such was our set up. Now for the dangers which we had to investigate. The first, and least important, group arises from very rapid changes of pressure. One feels pressure changes in one's ears, because if the pressure on the two sides of the drum is unequal, it is strained. The drum is a thin membrane across a bony passage which goes from the outside to one's throat, and incidentally was a gill-slit when our ancestors were fish. The air gets freely enough to the drum from the outside, unless, indeed, one has a lot of wax in the ear. But the passage to the throat, called the Eustachian tube, is normally shut. Most people can open it by holding the nose and blowing vigorously. When the air pressure is raised, there is some pain in the ears, which one relieves by blowing in this way, so as to equalise the pressure. Of course a diver cannot do this, as he has a window between his nose and finger. So he has to learn to open his Eustachian tubes. One method is to swallow. When you do so you may hear a clicking as the tubes open and shut. Another place where pain is often felt is in the frontal sinuses. These are air spaces in the bone of the forehead which ought to open freely into the nose. But the passage may be blocked, and commonly is when one has a cold. Some people cannot even open their Eustachian tubes when they have a cold. I can, but if my sinuses are blocked I bleed in a spectacular manner from the nose. One of the methods for getting into Norwegian fjords under water was to ride in a self-contained diving dress on a torpedo-like vessel called a chariot. Occasionally an inexpert charioteer put his chariot's nose down too fast. If so he was liable to hurt his ear, and one or two may have burst their drums. This makes one deaf for a month or so, but the drum generally heals up; and if a hole remains in it, although one is somewhat deaf, one can blow tobacco smoke out of the ear in question, which is a social accomplishment.

Airmen suffer from the same ear trouble. To a diver, this is almost unintelligible. For the pressure changes which airmen experience are relatively very slow. The quickest "dive" I have done was in the dry from one to seven atmospheres pressure (the equivalent of surface to 200 feet) in ninety seconds. Some divers have descended quicker than this, but not much quicker. The rate at which pressure increases is the same as a pilot would experience if his plane were diving vertically at 1,500 m.p.h., or twice the speed of sound. At this very fast rate of compression or decompression one gets pain in teeth which have been filled. During compression the air does not get in quick enough to cavities under the filling, so the tooth may cave in. During ascent the compressed air cannot get out, and the tooth may explode. One of mine perished in this manner.

The serious mechanical danger in rapid decompression affects very few people. But these few are born with weak patches in their lungs in which a bubble of air apparently gets nipped off, and these pockets may burst. The lung then collapses like the inner tube of a punctured tyre. Provided the other lung holds there is no great danger, though the patient must go to bed. If both collapse he dies. One of my colleagues, Dr. Rendel, had a lung collapse in this way after a dry "dive", and unfortunately it has repeatedly done so since. It has made him incapable of many kinds of hard work. The technical name for this condition, by the way, is pneumothorax, so called because there is air in the chest, between the lung and the ribs.

In 1940 the view was current in the Navy that it took a long time to learn to stand rapid compression, and I rather think the qualified divers encouraged this superstition. When I told certain officers that I did not share it, they said that no doubt trained biologists could learn quickly, but ordinary people could not. So I applied to the Communist Party for four tough guys of genuine working class origin with no experience of diving or compressed air work. We got every one of them up to a pressure of ten atmospheres (300 feet) in five minutes at the first attempt, though, of course, they were allowed to hold their noses. For one can hold one's nose when wearing the Davis apparatus, and at that time I was being asked for advice on submarine escape. I think one of them lost consciousness during the compression, but none of them asked for it to be stopped. I should say that, however psychologically tough one's subjects may be, about one in four would have difficulty in opening his or her Eustachian tubes, and would burst one or both ear drums if compressed at this rate. And it usually takes several dozen dives before one can open them without holding the nose or even thinking about it. I suspect the Navy's trouble was partly due to the fact that a man can usually learn to make a physiological adjustment quicker if you talk to him gently than if you shout at him Fortunately Warrant Officer Brown, who instructed personnel for the Admiralty Experimental Diving Unit, realised this fact fully, and is in fact one of the kindliest persons I know.

Before we go on to discuss the reasons why divers get killed, it is worth while describing some of the simple physical phenomena which one notices. Our chamber was filled from bottles containing air at 100 or 120 atmospheres' pressure. It cooled down a great deal as it left the bottles, but warmed up a bit on its way through the pipes. However, the air in the chamber was rapidly compressed by the incoming air and became intensely hot. In fact, the temperature rose from about 60° F. to 110° or more during a quick compression. We had a flexible metal tube attached to the inlet so that we could blow the cool incoming air onto our faces. The reason for this heating is, of course, the same as the reason why your bicycle pump gets hot. Effectively we were inside a bicycle pump in which the air was being compressed with a piston of air. Similarly when some of the air was let out, what was left cooled down rapidly, and a fog formed, which cleared up in a few minutes, but left everything damp. This had a serious effect on our watches. Either a watch is more or less airtight, in which case the pressure strains it very severely, or it is not, in which case fog forms in it during decompression, moisture condenses, the spring rusts through, and the watchmaker says you should not drop your watch into the water.

At ten atmospheres there is ten times as much air in a cubic inch as at normal pressure. You feel hot and try to fan yourself with a newspaper. But the resistance is so great that the newspaper tears to pieces. If you get hold of a large bit of cardboard for a fan, it is quite an effort to force it through the air. But if you then flap it towards a colleague four feet or so away, nothing happens for some seconds. Then you see his or her hair being violently disturbed. Your flapping has started a vortex ring which travels slowly, but owing to the density of the air, has a considerable mechanical effect. Rather to my surprise I found that a canary could fly at ten atmospheres, though it did not do so very well. Small flies refused to do so, though they could walk. I suppose they found the resistance of the air too great for their fine wings.

The human voice is greatly affected. Englishmen sound as if they were trying, not very successfully, to imitate an American accent. Some musical instruments are also affected. At eleven atmospheres my colleague Dr. Case found that a flageolet or "tin whistle" needed a greater effort to blow, but gave a fuller and rounder note than normal, rather like that of a recorder. A tuning fork gave its normal note, but the pitch of an oboe's reed was much reduced. We did not try any wooden instruments, as the compressed air soaks into the wood, and when it expands in the pores during decompression, quantities of resin are forced out.

Finally the air becomes effectively stickier in certain circumstances. In order to remove carbon dioxide one often has to breathe through a canister, rather like that of a gas mask, full of a coarse powder made of lime and soda. At atmospheric pressure this is easy, but at high pressure it may be very difficult. The volume of air per breath and the number of breaths per minute are unchanged. So at ten atmospheres one breathes ten times as much air per minute as at one, that is to say ten times the weight or ten times the number of molecules. At low pressures the flow is smooth, but at high pressures it becomes turbulent, that is to say eddies develop. So the resistance to breathing goes up, and one may breathe a very unpleasant dust.

After these preliminaries we come to the real dangers. They arise from the fact that all gases dissolve in liquids, and the amount dissolved is proportional to the pressure. Our body consists mainly of liquids, so at ten atmospheres there is, after a sufficiently long stay, about ten times as much nitrogen in solution in our bodies as normally. Our tissues use oxygen and make carbon dioxide, so these gases do not obey the rule so accurately.

All gases are poisonous. This has not yet been proved, but I believe it to be true, and hope to make it plausible to my readers. All solids and liquids are not poisonous, because they do not dissolve in our blood and tissues. Thus a lead shrapnel bullet under the skin is not deadly, though lead acetate is so; and we can swallow paraffin oil with safety or even advantage, though the same amount injected into a vein would be fatal. In particular, nitrogen is a poison.

If one is compressed to ten atmospheres one feels very abnormal. The feelings are rather like those of alcoholic intoxication, but perhaps more like those of mild intoxication with petrol vapour or nitrous oxide. I have little control over my thoughts, and my consciousness is invaded by childhood memories, and nonsensical words which seem to be very important. Another subject was first ashamed at finding a little nasal secretion on her hand, then ashamed at her shame, and finally convinced of the necessity either of divine grace or the extinction of her personal identity. At atmospheric pressure she is a materialist. Others merely "felt awful" or thought they were dying. A few were elated. I had no abnormal sensations, except occasionally a curious velvety sensation on the lips, first noted by Dr. Negrin, the former Spanish Prime Minister, who was compressed with me on one occasion. Others said that everything felt like ivory or that their fingers felt like bananas. A few saw things as if through a white mist.

For practical purposes, what matter are disturbances of behaviour. We used two tests. One consisted of putting little steel balls into holes, lifting them with the fingers and with special instruments. The test was originally designed to weed out the clumsier candidates for the profession of dentistry. One compared the scores at one and ten atmospheres. The deterioration was quite slight. A good scorer was still good under pressure. But a number of the subjects were detected cheating, for example, by using both hands. The other test was doing multiplications such as 7,486 × 5,137 as quickly as possible. Here the deterioration was enormous. Instead of getting about nine sums out of ten right, I usually got about three. One distinguished Fellow of the Royal Society put down two figures in five minutes, one of which was wrong, and said he thought it was a bloody silly test. The main difficulty with such tests was that the tester was usually as intoxicated as the testee, and often forgot to press the spindle of his stop-watch, or to take proper notes.

Captain Behncke, of the United States Navy Medical Corps, first showed that these symptoms disappear if a mixture of four volumes of helium and one of oxygen is breathed, that is to say the nitrogen in air is replaced by helium. Dr. E. M. Case and I showed that hydrogen is equally effective. We made up a mixture of one volume of air with nine of hydrogen. This contains only two per cent. of oxygen. But it contains as much oxygen per cubic inch as air at atmospheric pressure, and so as much oxygen is taken up by the blood going through the lungs. So it supplied all the oxygen we needed. On the other hand there was not enough oxygen in it to render it explosive. So it was safe to store it in a cylinder. Whereas with a possibly explosive mixture there is a chance that the friction as it leaves the cylinder may set it off. The moment we switched over from air to helium-oxygen or hydrogen-air we felt more normal within a few seconds, and were capable of doing arithmetic within one or two minutes.

A Swedish engineer called Zetterström independently, though slightly later, discovered that hydrogen was as good as helium. He used a mixture of four per cent. of oxygen with the gas, consisting of three volumes of hydrogen to one of nitrogen, which is made by "cracking" ammonia. He also used a nitrogen-air mixture for switching over from air to the mixture used at great depths, so that at no time was the mixture in his suit explosive. With these mixtures he descended to a depth of 450 feet and answered the telephone rationally. Unfortunately he was pulled up by means of a platform; and owing to some mistake, which has not been very adequately explained, this was done too rapidly, and he died of bubbles in the blood, in the way which I shall explain later. Since helium is almost a monopoly of one of the great American oil trusts, it will doubtless continue to be boosted. But hydrogen is probably as safe as helium, and certainly vastly cheaper. Zetterström's death was due to an error committed at the surface.

It is a surprising fact that argon has the same effects as nitrogen, and at somewhat lower pressures. As it does not combine with anything, this makes it fairly clear that the narcotic effect is simply due to nitrogen and argon getting in the way of the normal processes in cells. If so, it is reasonably sure that hydrogen and helium would have similar effects at very high pressures, and neon at an intermediate one. One minor point is worth noting. The narcotic action of nitrogen was discovered on men. Baboons compressed to fifteen atmospheres showed no abnormal behaviour. An eminent psychologist (who had not himself been under high pressure) gave a psychological explanation of the effect of compressed air on human behaviour. As a mistake under water can easily be fatal, the baboons and the psychologist between them probably have some deaths to answer for.

Oxygen is a poison of quite a different sort. There are two kinds of symptoms. At high pressure the symptoms are nervous. One ends up with loss of consciousness and a convulsion quite like an ordinary epileptic fit, except that occasionally the muscular contractions are violent enough to break a bone. Before the fit there are almost always vague feelings of discomfort. Usually, though certainly not always, the muscles of the face stiffen and begin to twitch. Some people get uncontrollable hiccups. There is never any confusion like that produced by nitrogen. Unfortunately certain people often get no warning signs, though I generally do so myself.

At pressures below three atmospheres one may last long enough without a fit to develop lung irritation. This begins as mild coughing, followed by pain, and develops into a pneumonia which may be fatal. However, it is of very little practical importance. At two and one-half atmospheres (50 ft.) I did not even start coughing for three and one-half hours, and when I knocked off after four and one-half, I had nothing worse than a chest pain which lasted for a day or two. Dr. Case had a very similar experience. Most people would get a fit long before this.

The most curious fact about oxygen poisoning is that the effects on the central nervous system are extremely variable in their time of onset, both between different people, and in the same person from day to day. Even after I had had two severe fits and crushed some vertebrae, I remained more resistant than the average. But after about a hundred experiments, in half of which I had had some nervous symptoms, I became so sensitive that I began to twitch after breathing oxygen for five minutes at atmospheric pressure. Of course, this may be attributed to hysteria, a conditioned reflex, or some such cause. But as I started breathing air through a mouthpiece, and nobody told me when the oxygen was turned on, neither explanation seems very likely. Other people varied irregularly. My wife breathed oxygen at ninety feet pressure on seventeen occasions. On one she lasted for eighty-eight minutes and knocked off with warning symptoms. On another she had a fit after thirteen minutes. Her other times were intermediate.

Besides this great variation in the same person, there are differences between different people. Some people always seem to be sensitive, and are clearly no good for under-water work involving oxygen breathing. It is very important to weed such people out. There is no way of predicting beforehand how anyone will behave. Men who had been on several commando raids, or got a G.C. for dealing with mines under water, crumpled up, while a woman who screams on rather slight provocation, or an elderly and rather flabby professor, were quite happy. Worse still, one could not predict very accurately from experiments in air to what would happen under water. I had one of my fits for this reason.

One of the naval ratings who was being trained in the use of oxygen under water was a boxer. While coming round from a fit he asked, "Who did that?" As he was lying down and someone was wiping him with a towel he probably thought he had been knocked out. The attendant answered, "Oxygen Pete". Oxygen Pete caught on. Would-be oxygen divers were first tested in No. 3 Chamber. In one corner of it someone wrote, "Oxygen Pete sits here." If several people had fits on the same morning, people said, "Oxygen Pete's in form to-day," and if one lasted unusually long one boasted of having got the better of him. I suppose a number of gods and devils started their mythological lives in some such way in the past. Fortunately Oxygen Pete arrived on the scene too late to be incorporated into a religion.

The oddest thing we found out was that oxygen has a taste. The textbooks say it is a colourless, inodorous, tasteless gas. At six atmospheres I described its taste as "like dilute ink with a little sugar in it". My colleague, Dr. Kalmus, described it as "like flat ginger beer". Anyway it is both sweet and sour. Of course, this is an example of what Hegel and Engels called the transformation of quantity into quality. In pure oxygen at six atmospheres there is thirty times as much oxygen in a cubic inch as in air at one atmosphere. And thirty times as much dissolves in a cubic inch of water. You don't taste sugar or salt dissolved in water till it reaches a certain concentration. Nor do you taste oxygen. Still it is rather striking that a gas with no sensory qualities at ordinary pressures develops them at high ones. In the same way ammonia and methane have quite a colour if you look through enough of them. The first men to go to Saturn (and by the way they will have to wear self-contained diving dresses) will notice this fact, for a spectroscope shows that the atmospheres of the outer planets are coloured by these gases.

The greatest of all dangers to divers remains to be described. An average man has about a litre of nitrogen dissolved in his body. If he stays for six hours or so in the air at two atmospheres, he will have two litres, and so on. It soaks in rather slowly. Organs like the brain and liver, with a good blood supply, take it up quickly, but those, like the joints and fat, with a poor blood supply, take some hours to fill up. Now if you have a liquid in which a gas is dissolved at a high pressure, and suddenly lower the pressure on it, the gas comes out of solution and forms bubbles. Ginger beer and champagne contain carbon dioxide under pressure, and froth when a bottle is uncorked.

Much the same happens in a man or woman. If you have been for an hour at a hundred feet, that is to say at a total pressure of four atmospheres and incautiously screw up the escape valve of your diving dress, it inflates until you suddenly leave the bottom. You shoot up to the top, and within a few seconds you are black in the face, and unconscious. If the attendant undoes your dress, you will die in a few minutes, and the post-mortem examination will show your blood vessels full of froth. As your heart cannot drive bubbles through your capillaries, you die of oxygen want. In such a case the only thing to do is to open the air vent and drop you back to the bottom again. The bubbles are at once compressed to a quarter of their size, and soon begin to dissolve again in your blood. A number of lives have been saved in this way.

Supposing, instead of coming up very rapidly, you do so in two or three minutes, the blood will have time to unload its spare nitrogen in your lungs on the way up. For on an average every drop of blood goes through your lungs about twice a minute. But within a short time you will be in severe pain. The commonest places for this pain are the joints, but one can get them elsewhere. You may also become paralysed. The joint pain is called "bends" because when one has it in the knee or elbow one finds it difficult to straighten the limb concerned. The pain has been described as unbearable. I don't believe it. I have never seen anyone sweating with pain from bends, which I take as a good rough sign of severe pain. But it is quite enough to stop one working efficiently, and may go on for days.

Bends are probably due to bubbles in the bags of synovial fluid which buffer the joints. A bubble in the nervous system is more serious. I have only had one. This was in the lower part of my spinal cord. For several days I had a burning pain in the skin of my buttocks. This gradually died down to a tickle, combined with a loss of ordinary sensation. Both of these are still there after six years. If I had lost most of the sensation from my right hand, the result would have been more serious. Other people have had bubbles which interrupted the paths to muscles, and therefore caused paralysis, and some have died from this cause.

If one is decompressed under conditions which just do not cause bends, a very common symptom is itching, often combined with redness of the skin. Nobody knows how this arises, though there are several guesses.

My father, Dr. J. S. Haldane, worked out the method which is universally used to avoid bends. He found that, however long an animal or a man had been exposed to compressed air, it is always safe to halve the pressure. Thus even after many hours at thirty-three feet of sea water, or two atmospheres, one can come to the surface at once. But after a long time at sixty-six feet, or three atmospheres, it is only safe to come up to sixteen feet, or one and one-half atmospheres. Then one waits until one has got rid of some of the excess nitrogen, comes up a further stage, waits again, and so on. For example, after half an hour to an hour at 175 feet, one comes up to seventy feet in three minutes, stops three minutes at seventy feet, three at sixty feet, seven at fifty feet, ten at forty feet, twenty at thirty feet, thirty at twenty feet, and thirty-five at ten feet. The total time spent in ascent is 101 minutes, or perhaps three times as long as one spent on the bottom.

Sir Robert Davis, of Siebe Gorman & Co., speeded up decompression by the following device. The diver comes up to the first stop, and then gets into a chamber like a diving bell with an open bottom. An attendant helps him out of his dress, and gives him oxygen to breathe. In consequence almost all the nitrogen in the blood passing through his lungs comes out of it, and he can be decompressed a lot quicker.

My father also recommended the use of mixtures of air and oxygen under water, so that the diver would take up less nitrogen. However, no systematic work had been done with such mixtures. The matter became urgent in 1943. It was foreseen that when we captured ports from the Germans they would leave behind them mines and obstacles such as sunken ships, which would have to be removed. Now you must be a very brave man indeed to hunt for magnetic mines in muddy water, especially if you have seen some of your comrades go up. You must be a man of superhuman courage if you know that, if you hear a mine beginning to tick, and go up to the surface quickly, you may be paralysed for life if you are not blown to pieces. There is another reason why you should be able to come up quick. In an air raid on Le Havre or some other recaptured port in 1944 a man in a boat was in no greater danger than the average Londoner at the same time. But if he was under water he might be killed by the shock wave from a bomb bursting in the sea several hundred yards off. For water is so incompressible that a shock wave must travel very much farther than in air before it fades out. So divers should come up during an air raid.

Clearly if the diver breathes a mixture of air and oxygen he will absorb less nitrogen than if he breathes air. Hence he can come up safely from a greater depth. So one wants to cut the nitrogen down as much as possible. On the other hand if he gets too little nitrogen, and too much oxygen, he will have a fit. It is safer to have a fit when clearing obstacles with a comrade ready to haul you up than when crawling under the *Tirpitz*.

But it is not a hundred per cent. safe. So my wife and I set out to find out the safest mixtures to use at various depths and for various times. There were some calculations to be done first, for the mixture in the diver's lungs is by no means the same as that in his bottle. Then we had to try the mixture. This meant going say to 70 feet pressure for half an hour. One of us would work while the other kept watch. Then we were rapidly decompressed. If there were no symptoms we repeated the experience the next day for three-quarters of an hour, and so on. If either of us got bends we generally took a day off to let the bubbles disappear.

These experiments were successful. According to the official tables, a diver who had been at a certain depth for a certain time was supposed to take forty-seven minutes to come up. We did it in two minutes without anything worse than itching, though I admit the naval officer who tried it next got a rather stiff shoulder. So the official time for an ascent from such a dive is, I think, seven minutes. But one could come up in one minute during an air raid without serious danger. The mixtures which we had tested in 1943 were used by the "P-parties" which cleared occupied ports in 1944. This was our main contribution to winning the war, though I gave a good deal of advice on all sorts of matters, from tanks to bomb-aiming, and some of it was accepted.

One of these matters was escape from submarines, and here Dr. Case and I had to deal with still another gas, carbon dioxide. Suppose a submarine is on the bottom and cannot rise. By the time this is clearly known the air is fairly foul. Now all the hatches of a submarine open outwards, so that the water pressure outside keeps them shut. They cannot be opened till the air pressure inside is equal to the water pressure outside. Men can get out of a submarine one at a time from a small escape chamber, or twenty or thirty at a time from a flooded compartment. Suppose you are at 300 feet, you let in water till the air in the compartment is squeezed into one tenth of its original bulk. You then put on your Davis apparatus, open the hatch, and ascend to the surface. At least you are supposed to.

But there will certainly be some extra carbon dioxide in the ship's air from the crew's breathing, even if the air-purifying apparatus is acting well. At ten atmospheres there will be ten times as much in each cubic inch. We were asked to find out how poisonous this gas was at high pressures. The average man loses consciousness in about five minutes at ten atmospheres when there is as little as three-quarters of one per cent. of carbon dioxide in the air breathed. This gives the same absolute amount per cubic inch as if he were breathing seven and one-half per cent. atmospheric pressure.

The standard set up was an inquisitor (Dr. Case or myself) and a rabbit (somebody else, after each of us had acted as rabbit). The inquisitor wore a respirator to absorb the carbon dioxide in the air breathed. If he kept it on he had the fun of seeing the rabbit lose consciousness and finally fail to respond even when his or her eyes were touched. Sometimes, however, the inquisitor got so intoxicated with nitrogen that he forgot to put his respirator on after taking it off to say something. Then there were two unconscious rabbits, and an observer outside gave the order to decompress when both appeared to have taken the count.

The Admiralty also wanted to know what happened if the water was very cold, as it is in the Arctic Ocean. So we used to lie in a shirt and trousers in a bath of water with melting ice in it until shivering became uncontrollable. This took about fifteen minutes for Case, and twenty minutes for me, as I am fatter. Then we were compressed, and any gas required was added. These experiments were not appreciably unpleasant. One feels a sharp pain round the neck at the surface of the water. The rest of the skin soon gets numb. One's resistance to high pressure gases is slightly, but not very greatly, lowered.

Dante said that the very worst sinners were frozen in ice. They were also exposed to compressed air ("*l'aër perso*" is his phrase, and the pressure would reach ten atmospheres at a moderate depth) and presumably to carbon dioxide from the flames. As one of the two people who have tried it, I can say that the great Italian poet exaggerated the discomfort of the sinners in question. I hope that if any reader has qualified for the eternal ice by the treacherous murder of a relative or benefactor, this may console him.

It now remains to draw the moral. The first point is that such experiments can and should be done on human volunteers. The Nazis did similar experiments on political prisoners and on Russian military prisoners. They killed many of them, but the information which they got was of little value.

These experiments were, in fact, almost as futile as they were cruel. For the important practical question to be answered is, how long a man can carry on with his work under unfavourable circumstances, not whether, after he has become unconscious, one can bring him round again. Experiments on animals are useful to show the kind of danger to be expected, but they do not tell exactly what a man can stand. This can only be done on human beings whose courage or curiosity will keep them going till they drop.

The second point is even more important, for few British people outside the British Union of Fascists defend the Nazi doctors. These experiments ought to have been done before the war, and done much more methodically than we were able to do them. It is monstrous that men should be exposed to dangerous environments, whether in war or in industry, before the most thorough tests have been done to see how men can stand up to the strain in question. And it is often possible to weed out those who will not stand up to it. Let me take an example from industry. Thousands of men and women have to inhale the vapours of solvents, for example, of benzene in the rubber industry. Some fall ill, some do not. No really quantitative work has been done to find out exactly how much benzene must be inhaled to produce symptoms of given severity in, say five per cent. of a group of people. If this were done, two things might be possible. First, the dangerous concentration of benzene vapour could be much more closely defined than at present. Second, it might be possible to pick out a certain group of workers (say the very fat, or those whose kidney function was below the average) as specially likely to be injured.

Such things will not be done until our industries set up physiological laboratories like the Royal Naval Physiological Laboratory for this honourable and sometimes dangerous service. The only bodies which are likely to insist on this being done are the Trade Unions. It was, in fact, a Trade Union, the Amalgamated Engineering Union, which started me on the work which I have described here when they asked me for advice regarding some of their members who had been killed in H.M.S. *Thetis*.

Compressed air is only one of hundreds of abnormal environments in which people have to work. All of them could, and should, be investigated.

OVERCROWDING AND UNDERCROWDING

FOR A PROPER UNDERSTANDING OF HUMAN SOCIETY we need knowledge of all kinds. A knowledge of economics is, of course, essential, but it is not sufficient. Biological knowledge is needed too.

Let us take a simple example. We may ask under what conditions large towns can exist. Clearly the town dwellers must get food; and this means first that there must be agricultural populations producing more than they need to keep them alive, and secondly, means of transport. Also the town dwellers must make goods to exchange for their food. But this is not enough. A dense population is much more liable to disease than a sparse one. So there must be some check on the spread of disease. The greatest killers in the past have probably been waterborne diseases such as cholera and typhoid fever. These inevitably spread in towns if the water is drawn from wells which are polluted by sewage.

There are two ways of avoiding this danger. One is a water supply drawn from the country. The Romans made aqueducts (or forced slaves to make them) for all their great towns, and this was one reason why their towns grew as they did. A slave in ancient Rome had a pretty bad time, but he got better water than an English king up to a hundred years ago. The other way is not to drink water, but beer, wine, or a beverage such as tea, made after boiling water, which destroys the germs of most diseases. Until our cities had decent water supplies it was safer to drink beer than water. However, the slogan "Beer is best" has been out of date for several generations. No one is likely to be any less healthy through the present shortage of beer, and many people will be the better for it. In the same way washing of the body and clothes keeps down lice, and thus prevents the spread of louse-borne diseases such as typhus fever; while cleaning up houses discourages the breeding of fleas and rats which carry plague.

However, we have a great deal more to learn about overcrowding and undercrowding, and we may learn something from a study of animal societies, not only of highly social animals with division of labour, such as bees, but of other animals which live in groups. Overcrowding and undercrowding may work on a simple chemical basis. Thus a little green worm *Convoluta* which lives in sandy beaches is killed if the sea water is diluted with an equal volume of fresh water. But 300 such worms in an ordinary dish survive quite happily. Between them they let loose enough of a protective substance to save themselves and their companions. But the very same worms are more easily killed by potassium chloride if they are crowded than when alone. Thus what is undercrowding in one context is overcrowding in another.

With many animals there is an optimum density at which the reproduction rate is greatest. This has been specially studied in food pests. When they are too scarce they may have difficulty in finding mates. Even where this was not the case, Park found that frequent mating stimulated female grain beetles to lay more frequently. When the density exceeds the optimum greatly, there is competition for food, but even before this becomes important, the mere jostling of beetles together may interfere with egg laying. The influence making for fertility may be purely sensory, or, as we should say in a human case, psychological. Thus Harrison found that a female pigeon in solitary confinement would not lay eggs. It was enough if she could see other pigeons, or even if she could see her own image in a mirror.

The most remarkable example of sensory influences is found in locusts. Uvarov discovered that in the migratory locust there are two distinct phases, the solitary and the social. The social form is darker, smaller, and develops quicker. Above all it differs in its habits. If its neighbours move in a certain direction it moves with them, and it readily forms swarms which may fly for hundreds of miles. The solitary form does not behave in this way. As the locust population in an area increases, the insects change from the solitary to the social form. Chauvin found that a young solitary locust brought up with a number of other locusts, even of a different species, grew up into the social form, even if it was only in society for one day out of four. The transformation occurred if the young locust was put in a glass tube surrounded by others, provided it had light. It only did so in darkness if it could touch its comrades. The adults only change if they can feel other locusts with their antennae.

Quite different effects are found in other insect species. Grassé found that winged termites, although physically mature, will not mate if kept in a nest with workers and larvae. But they do so if others are removed, even if they have never had the chance to fly off to found a new colony. Chen got nearer to human conditions by studying worker ants. When kept alone they dug holes in the earth, some quickly, some slowly. When two were put together the slow one speeded up and the quick one slowed down, but between them they generally did more work than alone, even though they did not help one another.

What has all this got to do with human beings? Not a very great deal with adults, but perhaps a lot with young children. Families are smaller than sixty years ago, and except in abnormal times like the present, we do our best to have only one mother in a house. This means that until they can get out to play in the street or a public park, or go to school, many children see little of other children. Of course, things are very different where they go to a nursery school or a crèche such as those which are part of every large factory in the Soviet Union, and of which a number were started as wartime nurseries in England during the war. What effect does this have on babies? In the Soviet Union many people think it makes them social beings at an early age. I might be a much nicer chap if I had not been a first-born child without a brother or sister till I was five years old. Or I might be less intelligent, or both. I don't know. But I do know that we want information on these questions, derived from observations on human beings, as well as on locusts and pigeons.

DRY HEAT AND WET HEAT

TO KEEP OUR TEMPERATURE NORMAL WE HAVE TO get rid of all the heat we produce in our bodies. This is about one hundred kilocalories an hour, when doing quite light work. If we lost none of it, our temperature would rise rather over 2°F. per hour, and we should be dead in five hours or so.

We lose some by warming the air round us, and by evaporating water from our lungs. When we get warm we unconsciously increase the flow of blood through our skins, so that we lose more heat per minute to the air.

This does not necessarily mean that our skins get redder. One may have quite a red skin when the blood in it is pretty stagnant, as it is in one's face on a cold day.

However, a time comes when increased blood flow will not get rid of all the heat, and then sweating starts. This does not mean that the skin gets wet. On the contrary, when the air is dry the sweat may evaporate the moment it reaches the surface.

Evaporation is a very efficient method of cooling. To get rid of 100 kilocalories an hour you only need to evaporate about 187 grams of water, or about a third of a pint. So if a man is in dry air at body temperature he need only sweat a gallon a day to keep cool. Actually this figure is too low, for the process is not quite efficient, especially if clothes are worn. But it is not far out. As everyone can sweat a quart or more per hour, and some people over a gallon, there is a very wide margin of safety.

But air is never quite dry, even in an African desert, much less in England. The more water vapour the air contains, the slower the sweat evaporates, and the harder it is to regulate one's temperature.

A very good measure of the effect of air on human beings is the wet-bulb temperature. Suppose we have two thermometers, one with an ordinary dry bulb, and the other with a bulb wrapped in a wick which dips into a water bath, this wet-bulb thermometer will always register a lower temperature unless the air is saturated with water vapour.

For example, when the dry-bulb thermometer registers 86° F., the wet-bulb thermometer will register 86° F. if the air is 100 per cent. saturated, 77° F. when it is sixty-seven per cent. saturated, 68° F. when it is thirty-nine per cent. saturated, and so on.

Once the air is fairly warm, it is the wet-bulb temperature, not the dry-bulb, which determines how the heat will affect a man. Still better results are obtained with what is called a katathermometer. This is a vessel filled with water at the human body temperature, and wrapped in a damp cloth. By measuring the rate at which its temperature falls, one gets a very good measure of the cooling power of the air. In particular it is affected by air movement in much the same way as a man. If the air is hot and dry, a light breeze cools one, because it helps the sweat to evaporate. But once all the sweat has evaporated, any increase in the wind brings more heat to the body.

So for each temperature and humidity there is a small range of wind speeds at which one is coolest. A hot wind can be very distressing, and even dangerous.

However, the wet-bulb temperature is a good rough measure of what a man can stand. My father was one of the pioneers in work on this subject, with special reference to conditions in mines. For example, he went into a level in Dolcoath tin mine in Cornwall where the dry-bulb read 94° F. and the wet-bulb 93.6°, so the air was almost saturated with water vapour. After an hour his mouth temperature was 101.5° F. and his pulse rate 138, though he had taken his shirt off. He gave up after an hour and three-quarters. On another occasion he stayed for over half an hour in dry air where the dry-bulb temperature was 182° F., and the wet-bulb 97°. His temperature had risen to 102.3°. But with a dry-bulb temperature of 136° and a wet-bulb of 89° he had no discomfort after an hour and a half and a very slight rise in temperature.

In very dry air one can stand temperatures well over boiling point for twenty minutes or so. My father said he drew the line when his hair began to singe if he moved his head quickly.

It is a good general rule that work is very uncomfortable if the wet-bulb temperature is over

80° F. and dangerous if it is over 90° F. However, individuals differ, and most healthy people can adapt to some extent. There is not much difference between different races. Skin pigment protects from sunburn, but not from heat.

During the war a lot of British men and some women had very thorough experiences of dry heat in the African desert, and of wet heat in Burma. Some died of heat stroke in each campaign. More would have done so but for the excellent experimental work on the subject carried out at the National Hospital, Queen Square, London. It is up to the survivors to see that similar work is carried out to protect miners, foundry workers, and others who are exposed to great heat in peace-time.

DUSTS

THE MINISTRY OF HEALTH IS ENGAGED IN TWO POSTER campaigns, one, urging us to hold a handkerchief in front of our faces when we cough or sneeze; and the other, to avoid venereal disease, though it does not tell us how to do so.

"Clean living," we were told, "is the only safeguard." If "clean living" means avoidance of sexual intercourse with people to whom one is not married, this is nonsense, and dangerous nonsense.

However, I am not going to deal with this question, but to point out that the Ministry of Health gave no warning against a danger which kills more people, and causes more sickness, than coughs and sneezes or venereal diseases, namely dust. To be more accurate, certain dusts; for some dusts seem to be harmless, and others are clearly good for health. The evidence as to what dusts are poisonous comes from the statistics of mortality in different trades, and unfortunately we have no figures later than 1931. But a dust which killed people in 1931 still kills them in 1949.

Let us see how we get evidence as to the harmful character of a dust. The kiln and oven men in the pottery trade, that is to say men engaged in making earthenware, china, porcelain, terracotta, and glazed tiles, had a mortality fifty-seven per cent. above the average. Their death-rate from phthisis was 127 per cent. above the average; that from other lung diseases 147 per cent. above the average. We naturally look for something wrong in the air which they breathe. If the sudden change from heat to cold and back were responsible, we should expect the kiln and oven men baking bricks and unglazed tiles to have the same high death-rate. Actually their death-rate was thirteen per cent. below the average, and their death-rate from consumption was half the average, though the sudden temperature changes may explain the fact that their death-rates from bronchitis and pneumonia were rather high. Furthermore we find that the pottery workers' death-rate from "chronic interstitial pneumonia", which is the Registrar-General's pet name for silicosis, was thirty-two times the average, and we need hardly go on to read medical reports on the lungs of dead pottery kiln men to conclude that dust kills a lot of them, though these reports certainly drive the point home.

The dangerous mineral dusts mostly contain silica, and come from sandstone, slate, anthracite, abrasives such as emery and the sand used in sand-blasting, pottery glaze, and a few other sources. Not all mineral dusts are harmful. Limestone quarrymen have a total death-rate twenty-eight per cent. below normal, and their death-rate from phthisis is less than half the average. Limestone masons and lime-burners who help to make cement are also healthier than the average. This has been known for many years. But private and public authorities go on using sandstone. One of the cathedrals at Liverpool is largely built of red sandstone. Many lives would have been saved had it been built of brick, concrete, or limestone. The decision to build it of sandstone killed a number of men just as surely, and a good deal more slowly and painfully, than if a man had been buried alive under the foundation as a human sacrifice. For sandstone masons inhale so much silica that their death-rate from phthisis is four times the average. There is plenty of limestone in the Pennines, at no great distance; but the authorities both clergy and lay, responsible for such a building, do not think in terms of human life, whatever they may claim to do.

Asbestos dust produces effects rather like those of silica dust, but it does not kill anything like so many people. On the other hand it is a good deal harder to detect by means of X-rays, so its victims are more likely to die or become invalids without compensation than those of silicosis.

Textile dust is pretty deadly in large quantities. Cotton blowroom workers, and strippers and grinders, who inhale cotton dust, had a death-rate forty-five per cent. above the average. They died not only of lung diseases, but of heart and kidney diseases. Wool dust also affects the kidneys. Wool spinners and weavers had over twice the normal death-rate from kidney disease, though it does not seem to hurt their lungs. No one knows how the kidneys are damaged. It seems possible that the lung cells, instead of being clogged up with wool dust as they are with silica or asbestos dust, break the wool down into substances which are carried by the blood to the kidneys. But the kidneys are damaged in the effort to excrete them. For every pound of textile dust inhaled by textile workers, I should think housewives inhale a hundredweight, though, of course, it is spread over many more people. The vacuum cleaner, which inhales textile dust without being poisoned, probably saves a lot of lives.

Of course, a small number of workers are exposed to much more poisonous dusts. The dangers of lead dust are fairly well known. Manganese compounds affect the parts of the brain concerned with posture, and give rise to stiffness, twitching, and difficulty in walking. Later on speech is affected, and emotional control may be lost. Hatters used to die on a large scale from inhaling mercuric nitrate dust, which is still sometimes used to loosen the rabbit fur from which felt is made. This not only rots the teeth, but causes a tremor called "hatters' shakes", and finally madness. The phrase "as mad as a hatter" is not funny. Hatters did very frequently go mad from mercury poisoning. However, more mercury poisoning seems to be due to the vapour than to dust.

Other dusts cause dermatitis. This is particularly common with explosives, such as "tetryl", whose dust particularly affects the inside of the nose. Trinitrotoluene and mercury fulminate also attack the skin. There is some evidence, though far from conclusive, that dust from tarred roads causes lung cancer. With almost every new industrial process there is a new possible danger from dust. It is up to the workers to see that these dangers are investigated before, and not after, several people have been killed, and hundreds made ill.

Syed. Jeelani

D.D.T.

DURING THE WAR A NUMBER OF INSECTICIDES WERE developed on a very large scale. Perhaps the most successful, and certainly the most publicised of these is an organic chlorine compound generally known as D.D.T.

One of its most striking properties is that it can kill an insect without being eaten, or even dusted over the skin. If a fly settles for quite a short time on a surface containing a small amount of this compound, it absorbs enough through the pads of its feet to die in a few hours at most. D.D.T. has been most extensively used in the tropics, where insects are a far greater danger to human life than in cooler climates. It was dropped in powder from aeroplanes in front of our advancing troops in Burma to kill mosquitoes and ticks which infect men with "scrub typhus" fever. It has been sprayed onto cattle in Africa to kill the tsetse flies which settle on them and carry various diseases. It may even be possible to rid a whole district of tsetse by such methods. And it is quite efficient against house flies. If a little D.D.T. is added to paint or distemper, flies which settle on the wall soon die. "The incorporation of D.D.T. in paints and distemper is now an established procedure, and the practice seems likely to be extended in future," writes a doctor discussing the matter.

It would be very pleasant if, by simply distempering a house, we could ensure its freedom from flies. But would it be safe either for the inhabitants of the house, the painters who distemper the walls, or the workers who make the distemper? This is not so certain.

Perhaps the most striking experiment on the dangers of D.D.T. was done at the recently established Royal Naval Physiological Laboratory last year by Dr. R. A. M. Case and his technical assistant Mr. Ireland. Their results were published in the *British Medical Journal* after the end of the war. The naval authorities were naturally impressed by the possibility of keeping down mosquitoes and other insects in ships in the tropics by using D.D.T. in the paint. But it is better that a few members of a crew should get malaria than that a large number should be poisoned. To test this possibility Case and Ireland used a small airtight chamber six feet across and six feet high. It was kept hot and damp so that they sweated constantly, and they wore trunks only. It was first painted with an ordinary paint and sprayed with oil. They stayed in it forty-eight hours, and as they had to sleep with their naked backs against the oily wall, they were in close contact with the paint. However, they took no harm. Then the chamber was painted with a spray containing two per cent. D.D.T., and they did another two-day spell.

During these days they did not notice much except a smarting of the eyes, and a period when everything looked yellow. The smarting may have been due to something else in the paint.

But a day after coming out they felt touchy and tired, and gradually got worse. Three days later they had pains in the limbs and joints, and one of them had to go to bed. These pains lasted about a month. There were various nervous symptoms visible to others, such as tremor of the arms and altered reflexes. The hearing was affected, and sensation lost in the skin. There was also a mild anaemia, and other changes in the blood like those of lead poisoning. Larger doses kill mammals, the liver being specially attacked.

It is clear that if a ship's crew was exposed to this sort of poisoning in a milder form for some months there might be a lot of slight illness which would lower their efficiency and probably raise the number of arrests for minor offences, even if there were no clearcut cases of poisoning. The Navy presumably turned down D.D.T. for use in ships in the tropics. Are we justified in allowing its use in paints and distempers in our homes? I don't know the answer. The effects will certainly not often be so severe as those on Case and Ireland.

But some babies will lick anything. A number of Australian children were poisoned by licking raindrops which had run over lead paint. And housepainters get a good deal of paint over their skins. The Building Research Station, I believe, undertakes some physiological research. But I doubt whether they do any experiments as drastic as those which are in the day's work of the naval physiologists. Now that the effects of a fairly severe dose of D.D.T. on men are known, it would be quite easy to test the safety or otherwise of different paints and distempers, looking for some of the milder symptoms which Case and Ireland developed, such as the appearance of abnormal kinds of blood corpuscles. If this is not done, I do not suppose that many people will die or even become seriously ill. But there is quite a real possibility that millions of people will suffer slightly in health.

D.D.T. is on the market for all sorts of purposes. It was even on sale at the National Cage Bird Show, for delousing canaries. The public has not been adequately warned that it can harm men, and even canaries, as well as insects. It is a wonderful insecticide, and it would be a very great pity if as the result of a few avoidable cases of human poisoning, it were not used as it should be. I have often urged that physiologists should investigate the dangers of new chemical compounds before they have killed people or seriously injured them, and not afterwards. Here is a case in point. Unless Members of Parliament who take the people's health seriously raise the matter, it is unlikely that anything will be done. But if the matter is raised, the men who can investigate it are waiting.

A CURE FOR TUBERCULOSIS?

TUBERCULOSIS IS NOT AN INCURABLE DISEASE TO-DAY. A great many children develop tuberculous glands in the neck and recover completely. Adults with phthisis are often cured by sanatorium treatment, surgical operation, or both together. Nevertheless at best the cure is slow, and it is often incomplete. And no drugs are of any great value, though, of course, they can be used to treat such symptoms as coughing.

To-day there is definite evidence that a rapid and complete cure is possible. The hope may be a false one. I should not be prepared to bet more than three to one that the problem has been solved. But the evidence is certainly worth putting before the public. When penicillin proved its value, a number of substances were prepared from moulds which killed bacteria when cultured on artificial media. Many of them are no use in medicine, either because they are almost as poisonous to men and animals as to bacteria, or because they do not penetrate the tissues where the bacteria are at work. The American biochemist Waksman prepared two extracts from different moulds living in the soil, which prevent the growth of tubercle bacilli outside the body, and may actually kill them. One of these, streptothricin, caused such mortality when injected into infected guinea pigs that it would have been wrong even to try it on human beings.

The other, streptomycin, was injected into a number of guinea pigs which had been experimentally infected with human tuberculosis. In a typical experiment forty-nine animals were used. Seven weeks after infection, twenty-five were injected with streptomycin either daily, or every six hours; the other twenty-four were not treated. After twenty-four more weeks, seventeen of the untreated guinea pigs and only two of the treated ones had died. One of these two had only slight tuberculosis All the survivors were then killed and examined. Some of the treated animals had no signs of tuberculosis at all. A minority had a few tuberculous. glands such as are common in human children. But a few living tubercle bacilli were found in some apparently healthy animals.

Drs. Feldman, Hinshaw, and Mann of the Mayo Clinic in Minnesota, who published these results, refuse to use the word "cure" even of guinea pigs, but the facts speak for themselves. Nothing further has been published, but Dr. Feldman, in the Harben Lecture to the Royal Institute of Public Health in London, has described the effects of streptomycin on human tuberculosis. It was only used on very severe cases. The symptoms cleared up completely in a number of cases of phthisis and of lupus (skin tuberculosis). Even more striking is the fact that most, though not all, of the treated cases of tubercular meningitis recovered. This disease has so far almost always been fatal.

In spite of such remarkable successes, Dr. Feldman merely says that the results are highly encouraging, but adds that the facts do not warrant the conclusion that an ideal drug for the treatment of clinical tuberculosis has been found.

Of course, it is quite possible that the remissions will only be temporary, and that the disease will develop again. This possibility will remain until the patients have been free from symptoms for five years or so. The reason for this doubt is that bacteria develop resistance to other similar substances. And it may be that a few remain behind in apparently cured patients. If so the disease may start again after some months or years, and streptomycin will have no effect on it. Nevertheless a number of people who would have died without treatment are alive to-day.

The drug does not seem to be dangerous to human life, but a small fraction of the treated patients develop giddiness, and have some trouble in walking when they leave their beds. Its action is not confined to tuberculosis. It has a dramatic effect on tularemia and very probably on plague; and is being tried on leprosy.

So much for the bright side. Unfortunately there are two sides to this story. Waksman, and his colleagues, Bugie and Schatz, purified streptomycin. But it is one thing to make enough of a pure substance to determine its composition, and a very different one to make it by the hundredweight. Pure streptomycin is being made by Merck and Co. of Rahway, New Jersey, at the rate of more than a hundredweight a month, and sold at a price which suggests that they are making good, but not fantastic, profits on it. But they do not disclose the processes by which it is purified. Very likely there is nothing peculiar about them, and it would be difficult to take out patents to cover them. At any rate, they do not state the methods used, and there is no method of making them do so. The stuff must be purified. One of the earlier preparations used by Feldman and his colleagues contained an impurity which killed one guinea pig and made others ill. If the drug is even half as useful as it appears, and only ten million tuberculosis humans are to be treated, the world demand will be five or ten tons per day.

As a result of the "iron curtain" of secrecy,* workers in various European and Asiatic countries will have to start researches on purification from the beginning, and probably some hundreds of thousands of people will die on account of the delay. Many readers may know at least one such person. If this were pointed out to the directors of Merck and Co. they would probably answer that they had spent millions of dollars on research, and that if they published their methods they would go bankrupt, and would certainly never attempt such research again. This is probably quite true. The blame for such conduct does not rest on individuals, but on the economic system. I do not think that a State would dare to do such a thing. Supposing a Czechoslovak government laboratory discovered a cure for cancer and kept the details secret, world public opinion would probably force them to disclose it.

It is a familiar anti-socialist argument that States are more ruthless than private individuals. I think that the above facts disprove it. But it is the capitalist system, rather than original sin, which makes them ruthless.

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*Obviously modelled on that surrounding atomic energy release.

Meanwhile there is nothing to be done in this country but to start making streptomycin. It is, of course, a gamble. So was the atomic bomb. It may not be as useful as appears at first sight. But an aeroplane can crash on its trials, or a battleship be sunk by a single bomb. Yet we go on building them. If Members of Parliament, especially for Scotland and Wales, which are more tuberculous than England, put sufficient pressure on the Government, we shall get to work on it at once. Otherwise we shall wait till a large number of experts have been a hundred per cent. convinced, and the Treasury has gone into the financial side. During the months taken by these processes a good many thousand people will have died. If every tuberculous man and woman, and every parent of a tuberculous child in Britain, would write to their M.P. next week we could and should get off the mark. I hope that this article will start a national movement for armaments against the tubercle bacillus, which has killed more of us than the Germans ever did.

WAR ON WEEDS

FOR AGES IT MUST HAVE BEEN KNOWN THAT PLANTS kept in a shady corner often grew towards the light. If you believe in a life-force, or something equally ill-defined, you will regard such a tendency as natural, and not investigate it further. If you think materialistically, you will want to know how this growth, which is obviously useful to the plant, is achieved.

In 1881 Charles Darwin, who was a great experimenter as well as a great theorist, wrote a book on *The Power of Movement in Plants*, in which he stated that "when seedlings are exposed to lateral light, some influence is transmitted from the upper to the lower part, causing the latter to bend". He did not discover the nature of the influence. In 1911 a Dane called Boysen-Jensen found that if he sliced off the top of a growing barley shoot and put it back again with a fine film of gelatine between it and the rest of the shoot, the influence was still transmitted, while it would not pass through watertight films. Later Kögl, Erxleben, and others, mostly in Germany, actually isolated chemical substances which, in extraordinarily small quantities, stimulate plant growth, and showed that they are formed in the growing point of a shoot and pass down in the sap on the shaded side of it.

All this sounds interesting but very remote from practical agriculture. To judge from a series of communications published in *Nature* on April 28, 1945, it may prove, though quite indirectly, the means of making Britain much more self-sufficient as regards food supply. The most easily prepared of these plant hormones is indolyl-acetic acid. This is such a powerful stimulant that if it is added in a concentration of under one part in ten million to a watery solution in which plants are growing, it will kill the majority of species. The roots cease to lengthen, the leaves curl up in a characteristic way, and so forth. Similarly one can kill a man or an animal with an over-dose of the hormone from the thyroid gland, of which a small amount is absolutely necessary for normal growth.

Nutman, Quastel, and Thornton, at Rothamsted Experimental Station, started from the observation of a Chinese colleague, Chen, that the bacteria which fix atmospheric nitrogen in clover roots produce a hormone which makes them curl up. They found that though it is poisonous in water, it soon disappears from soil. But a chemically related substance, sodium 4-chloro-2-methyl phenoxy-acetate, persists in soil for some weeks, and has similar effects. Fortunately it has much less effect on cereals and grass than on most other plants. Slade, Templeman, and Sexton, working for Imperial Chemical Industries, had been secretly testing this substance among others for some years, and Blackman, at the Imperial College, London, also experimented with it. No doubt it will soon be on the market under a trade name.

The amounts needed are extremely small. Slade used one pound per acre, Blackman as little as a quarter of a pound. This is dissolved in about a hundred gallons of water, and sprayed. In these quantities it does not harm cereals or meadow grass, nor peas, onions, and leeks, although root crops such as the turnip and beet are very sensitive to it. But it completely wipes out a number of annual weeds, such as yellow and white charlock, and poppies. Some perennial weeds, including buttercups and horsetails, are killed; but unfortunately docks, stinging nettles, and bracken, stand up to it. Where weed infestation is serious, the effect may be enormous. Blackman obtained a ninety per cent. increase in one of his cereal crops. It is still too early to suggest what effect it would have on the wheat, oats, and barley production of this country, but if it raised it by five per cent., this would be of very great value.

Heavier doses will kill off all kinds of plants, including grasses and clover, and this may be of great use in improving pastures. For the poison disappears from soil in a few weeks, and after this a new crop of meadow grass can be sown. It is very important that the soil is not permanently poisoned. Some weed-killers contain copper and arsenic; and these may remain in the soil for many years, and may harm valuable plants, or even make them poisonous to men.

Incidentally an ounce should be quite enough to eradicate the weeds on a fairly large lawn, including mouse-eared chickweed, which is not touched by iron ammonium sulphate, though this is very effective against plantains and dandelions. So this discovery may mean not only cheaper bread, porridge, and beer, but better cricket, lawn tennis, golf, and bowls. For I have no doubt that the turf of our sports grounds, even where they had not been dug for victory, deteriorated during the wars.

It is probably only the first of a series of similar discoveries. The other plant hormones, and the substances related to them, are a good deal harder to make in a laboratory, and cannot yet be made on a factory scale. But when they are made, it is likely that a different group of plants may prove specially sensitive to them. For example, one of them may prove to be harmless to beet and turnips, while active against their weeds. Or perhaps it may be very effective against bracken.

Once more the value of pure science, or, as I prefer to call it, long-term research, is demonstrated. When one discovers a fundamental fact, one rarely knows what will be its practical value if any. Darwin and Boysen-Jensen may have thought that their work would produce straight trees. They would never have guessed that they were on the track of a super weed-killer.

On the other hand if agricultural research workers had realised the poisonous nature of an overdose of these hormones, the work would have been done earlier, and the lives of a number of merchant seamen who died to bring us wheat, would have been saved. The gap between fundamental research and its application is far too wide. It will only be bridged when we have far more workers on fundamental research, and when they spend a part of their time in peace, as most of them have done in war, in the practical application of their special knowledge. The experience of the Soviet Union suggests that this will be far easier under socialism. In England a professor who takes time off to work for a private firm is very properly censured, though he is allowed to do public service. In a socialist country all applied science is public service, and the gap between theory and practice is narrowed. That is one reason why more and more scientists are becoming socialists.

A GREAT ANNIVERSARY

ON DECEMBER 21, 1846, THE FIRST SURGICAL operation under an anaesthetic was done at University College, London. The anaesthetic used was ether. This was almost certainly the first use of an anaesthetic in England for a serious operation.

The pioneer in this field was the great chemist Davy, who showed that nitrous oxide, or laughing gas, was an anaesthetic. However, if you breathe it pure you get no oxygen and soon go black in the face. And a mixture with air usually contains too little oxygen or too little nitrous oxide. So either you do not lose consciousness fully, or are suffocated. There is no harm in being slightly suffocated during the extraction of a tooth, but it would be fatal during an operation lasting half an hour. So nitrous oxide can only be used in a major operation if it is mixed with the right amount of oxygen, and even in dentistry such a mixture is desirable.

The vapour of ether was first used as an anaesthetic in America. There is some doubt as to who was mainly responsible, though Wells probably deserves most of the credit. It is also said that the effects of ether were first observed at ether parties, where the guests used to breathe or drink ether to get drunk.

This has the advantage over alcohol that one recovers much more rapidly, but it is certainly more dangerous. Ether was probably used in Scotland a few months earlier than in England, and Simpson soon introduced chloroform at Edinburgh as a rival anaesthetic. Ether is very inflammable, and sometimes explosive, while chloroform is not. This was a very serious matter before the days of steam heating. Also ether is more apt than chloroform to cause coughing and struggling if it is used to "put the patient under". Nowadays the anaesthetist usually makes one unconscious with ethyl chloride, or some rapidly acting vapour and then switches over to chloroform or ether. However, occasionally ether is used from the start. The last time I had a serious operation they used it on me, and I found the experience delightful. Still many people dislike it.

Since those early days a number of other gases and vapours have been used, but none have been very widely adopted. Other anaesthetics are injected into a vein in liquid form, sometimes in conjunction with inhaled ether or chloroform. Finally it is possible to block the sensory nerves leading from a part of one's body, without blotting out consciousness. This can be done by injecting a drug near a nerve, or inside the backbone.

No surgeon thinks of doing a serious operation without an anaesthetic. But, unfortunately, although it is a century since Simpson first used chloroform in childbirth, hundreds of thousands of babies are born every year in Britain without any attempt to alleviate the mothers' pain. It is not always necessary, and it is often quite sufficient to dull the pain without making the mother quite unconscious. But an anaesthetic should always be available.

How do anaesthetics act? There are plenty of theories, but nobody knows for certain. All anaesthetics show two properties. They are soluble in water, and also in oily substances. Because they are soluble in water, the blood can take them up, and carry them round to all parts of the body. Because they are soluble in oil, they can get through the oily films which surround the cells, and penetrate into the watery protoplasm inside them. Probably every substance with these two properties is an anaesthetic unless it has some other effect before it reaches a high enough concentration to make one unconscious. A substance like sugar or salt which is soluble in water but not in oil is seldom an anaesthetic, though magnesium chloride is one when injected into a vein. Nor is a substance like camphor or castor oil which is soluble in oil but not in water. Anaesthetics probably act by slowing down various processes, including oxidation, which takes place in living cells. They can interfere with other organs besides the brain. For example, chloroform can damage the liver very severely, and many people have died in consequence. This is one reason why ether is more often used than chloroform. How they act is far from clear. But a new light had been thrown on it by the remarkable discovery of Captain Behncke, of the U.S. Navy Medical Corps, and his colleagues, that nitrogen and argon are narcotics. If you breathe pure nitrogen or argon you fall down unconscious with oxygen want. If you breathe them mixed with enough oxygen at ordinary pressures nothing happens. But if you breathe them at high pressures, even with plenty of oxygen added, you become silly. No one has breathed them at a high enough pressure to become quite unconscious, but I have found that in air at ten atmospheres' pressure, the sense of pain is already greatly dulled.

Now nitrous oxide is about forty times as soluble in water as nitrogen, and in consequence the blood takes up enough of it at an ordinary pressure to act as an anaesthetic. But weight for weight, nitrogen, nitrous oxide, and chloroform are about equally narcotic, and ether distinctly less so. Only you would need about thirty atmospheres' pressure to force as much nitrogen into your body as the amount of nitrous oxide or chloroform that you can take up at an ordinary pressure. Since nitrogen and argon do not combine with anything in your body, this means that they simply act by getting in the way and slowing down chemical processes. It is quite possible that the rare gas xenon will prove to be the ideal anaesthetic. At present it cannot be prepared in large enough quantities, but if air is liquefied on a vast scale, as it is in connection with underground burning of coal in the Soviet Union, it may be practicable to use it.

However that may be, we have had other quite good anaesthetics for a century, and it is a scandal that we do not use them as they should be used.

THE LAYMAN'S VIEW OF NATURE

I AM NOT GOING TO TRY TO TELL YOU WHAT NATURE is. The question with which I shall try to deal is how we should regard nature, not only intellectually, but also emotionally, Here there is a very sharp contradiction in human thought. To take an example, on the one hand we describe certain conduct as "unnatural vice". This conduct is abnormal, but it is not, as a matter of fact, unknown among animals other than ourselves; however, we regard this description as an extreme condemnation. On the other hand, if we read St. Paul we find that he said that "natural man receiveth not the things of the spirit of God." So neither natural nor unnatural conduct seems to be very satisfactory! We see what I think is essentially the same conflict of ideas and the same unsatisfactory view of nature in T. H. Huxley's antithesis of the cosmical process of nature and the ethical process in which we are concerned as human beings. I think that a contrast of that sort is inevitable if we regard nature as a planned whole; but as a matter of fact, nature is full of strife of all kinds, and the strife of our morality with nature in general is only one incident in that strife. Indeed, from the point of view of a student of nature who was not particularly interested in man, it would be a very small element compared, for example, with the strife between the enormous forces which, on the one hand, build mountains and, on the other, level them down, or the still greater forces which are concerned in astronomical events.

We have to recognise that nature is the realm of strife and not something planned; but apparently in order to be able to see that some principles run right through nature it was necessary for human thought to pass from an animistic stage, wherein every natural object, such as a tree, a brook, or a thunderstorm, was inhabited by some spirit more or less similar to the human mind, to the stage of regarding nature as created or controlled by a single intelligent being. Personifying nature, to some extent, by this way of thinking has undoubtedly left traces in the thought of even the most atheistic of us.

We have to ask ourselves, then, what is the alternative to this religious view of nature? As a scientist I reason about nature. For example, I have attempted to reason about the evolution of animals, plants, stars, and so on; but why have I done this about natural phenomena rather than about, let us say, economic phenomena? One reason is a very simple one. It is because I like nature. Nebulae and earthworms both please me. They did not please the men of the early historical period so much, whatever may have been the case with primitive men, of whom we know very little. Our ancestors, so far as we can judge of them, were so obsessed by human notions, such as the notions of utility and honour, that they had to pass through the stage of regarding nature as "the works of an Almighty hand" before they could permit themselves the pleasure of enjoying it; and we, too, have not learned our lesson thoroughly. I will go so far as to say that I think that the decay of religion has probably had a bad effect on art, because it has lessened the artist's fidelity to nature. I quite appreciate the desire of a painter from time to time to paint something queer, but the queerest imaginations of the surrealists are not half as queer as what one sees in an ordinary microscope. What I think is wrong with these imaginative products of art—whether they are medieval representations of human beings with horns or wings where these things ought not to grow, or surrealist pictures of human beings with eyes in the middle of their stomachs, in the palms of their hands, or in their feet—is that they have not passed the test of natural selection.

I want to suggest that in our thought and feeling about nature, natural selection should, for some purposes—although very emphatically not for all purposes—replace the idea of a Creator. It is not that we should reverence or worship natural selection as some eugenists apparently do, but I think that we should respect it in the sense of realising that animals and plants in their natural state have passed the test of natural selection and are to that extent respectable. If you want surrealist animals you can look at mutant forms of natural species which have not passed this test. You can go to a poultry and pigeon show, and you can see, for example, pigeons like the breed called Fairy Swallows, which have wing feathers growing out of their feet, and are almost incapable of flying. You can see Polish and Houdan fowls with a crest of feathers falling down over their eyes so that they can hardly see. You can go to a biological laboratory and see insects with legs growing out of their eyes. But these animals are not respectable in the same way as are the natural forms. I repeat that it is of the utmost importance that we should not worship natural selection, nor any hypothetical life force behind evolution. If we do, we shall probably end up with something like Nazi morals. But we should recognise that it is an aesthetic as well as a biological criterion.

I would go further and suggest that invertebrates might fill the place in art which the supernatural did in the past. If my portrait had been painted 500 years ago it would probably have been in a group including the Virgin and Child in the middle, one or two angels, and perhaps a small devil in the corner being socked by one of the angels. If it were painted to-day I should like the painter to add one of the small insects with which I work, represented as being, say, three feet long, and painted as carefully as an angel or a devil. They are, in my opinion, extremely beautiful creatures. Painters have not discovered the microscope or the telescope. In addition, we have got to try to realise the past of our planet. Perhaps the first serious artistic attempt to do so is Walt Disney's *Fantasia*, but much as I admire that film it could have been very considerably more accurate. Above all, I think that an artistic and, if you like, a poetical appreciation of the biological past of our planet should try to bring out the tragic side of evolution, the vast hosts of beautiful species which are now dead. I particularly mourn for the beast called Thoatherium, one of the Litopterna, which I suspect was the most beautiful animal which ever existed. It was like a racehorse, but considerably more streamlined.

We are all of us cut off from nature, and not only the town dwellers. It is perhaps important to remember something that we sometimes forget: that an English field is as much a human product as is a London street. It is only on the seashore, on the moors, and in a few forests, that we see nature anything like what it was before man interfered with it. Yet if we are intellectually and emotionally cut off from nature, we suffer a loss which is hard to define, but which I will try to explain. The inevitable emotional crisis of our lives, birth, love, and death, are essentially natural events which we share with other animals, and particularly with the other mammals. These events fit into nature better than they fit into civilisation. All three of them are, from the point of view of a mechanised civilisation, indubitably messy processes. Our ancestors surrounded them with religious acts: churching, baptism, marriage, funerals, and so on. Without that background they lose something. We can regain that loss, and more than regain it, if we come to see them as part of the great rhythm of nature. Probably the relations between man and wife are the most natural thing in most urban people's lives to-day, but because they are part of nature rather than civilisation, we have surrounded them with ideas like sin and dirt. I believe that the best way to overcome this is that children should see animals going through their natural life cycles of birth, mating, and death, and taking these things as they come, as we all must do.

We have to steer our way between two evils. One evil is to regard natural events either as being sinful, as physiological love is according to the Roman Catholics, or as a punishment for sin, as death is according to all Christian doctrine. The other danger, which is equally serious, is to go any distance in the direction of worshipping nature: for example, to suppose that our natural desires for sexual satisfaction ought to override our social obligations, or that children born with an abnormality should be allowed or encouraged to die just because they would do so in a state of nature. Nature deserves our admiration, but not our worship. Nor does any postulated creator of nature. If we took the orthodox view that the Creator had made the larger objects of nature, such as heavenly bodies, separately, and had also created a few of each species of animal or plant and endowed them with faculties of reproducing their like, an unbiased view of nature would lead to a rather strange conclusion. The Creator would appear as endowed with a passion for stars, on the one hand, and for beetles on the other, for the simple reason that there are nearly 300,000 species of beetle known, and perhaps more, as compared with somewhat less than 9,000 species of birds and a little over 10,000 species of mammals. Beetles are actually more numerous than the species of any other insect order. That kind of thing is characteristic of nature.

I would say that the more we know of nature, the more we admire it, and even love it; but the less we are inclined to worship it, and the more morally degrading becomes the worship of its Creator, who, if he existed, lavished as much care on tapeworms and tubercle bacilli as on antelopes and oak trees.

Nevertheless, we cannot understand ourselves or our neighbours adequately except against the background of nature, from which we spring. What we must not do is to follow Wordsworth when he said:

> "One impulse from a vernal wood
> May teach you more of man,
> Of moral evil, and of good,
> Than all the sages can."

From a contemplation of nature we can certainly learn a great deal about man, but moral evil and good are mainly our own contribution. We find only the merest traces of them in the higher animals.

We ought then for our own good to have access to nature and knowledge of it. To my mind, it is monstrous that any child should grow up without some acquaintance with nature, and, above all, I would say without an opportunity for intimate knowledge of some individual plants and animals. It is true that the average pet animal in London has a rather short life, but I believe that it would be possible even for every London child to have room for a small aquarium in which fish or newts could live for a reasonable time and beget sons and daughters, or to have some other opportunity of seeing what non-human life is like. I think it is as monstrous that an educated man should be ignorant of the Theromorpha as of the Ancient Britons or Teutons or palaeolithic man; all of them are our ancestors, and their study is relevant to us.

But is that all? One thousand five hundred years ago our ancestors recognised no duties outside th circle of kinsfolk. Today we recognise duties to a mankind, although our thought is so bound up wi the idea of duties to our kin that we have to disgui that fact by using metaphors such as the brotherhood of man. We are also beginning to recognise duties to the higher animals, although so far we can only say that we have the negative duty of not causing them unnecessary suffering. Have we any duties to plants and inanimate nature beyond preserving them for the delight, instruction, and use of our own species? I do not know the answer to that question, but I expect it is yes. It is a poor man who does not love his country, which is not the same thing as loving his countrymen. That is something in addition. If we love it, then I think we have a duty to it. Only posterity is going to be able to decide this question of whether we have a duty to nature, but on the general principle that every step in man's technical achievement broadens the sphere of his duties, I expect that posterity will decide it in the affirmative.

The particular duty of intelligent men to-day in regard to nature is, I think, a duty to themselves and to their fellow-men, rather than to nature itself. In our dealings with nature we cannot avoid thinking in metaphors of religious origin; for example, that it exists for our use (or for some other purpose) or that it obeys laws. We have to know nature as it is, and thus to secularise our conceptions of it and our treatment of it. As we come to study nature—particularly those of us who devote much of our lives to that study—we gradually approach a world view in which bacteria in our own flesh are as natural and as interesting as grass on a bank, in which our deaths and those of our friends are incidents in a process which we cannot but admire, even though we do our best to modify it; and we see that the struggles between classes and nations are phenomena susceptible to the same kind of analysis as the phenomena of nature, and, therefore, capable of control and ultimately elimination when we understand them scientifically. In fact, we can only begin to consider scientifically "What Is Life" after we have got accustomed to thinking scientifically about nature.